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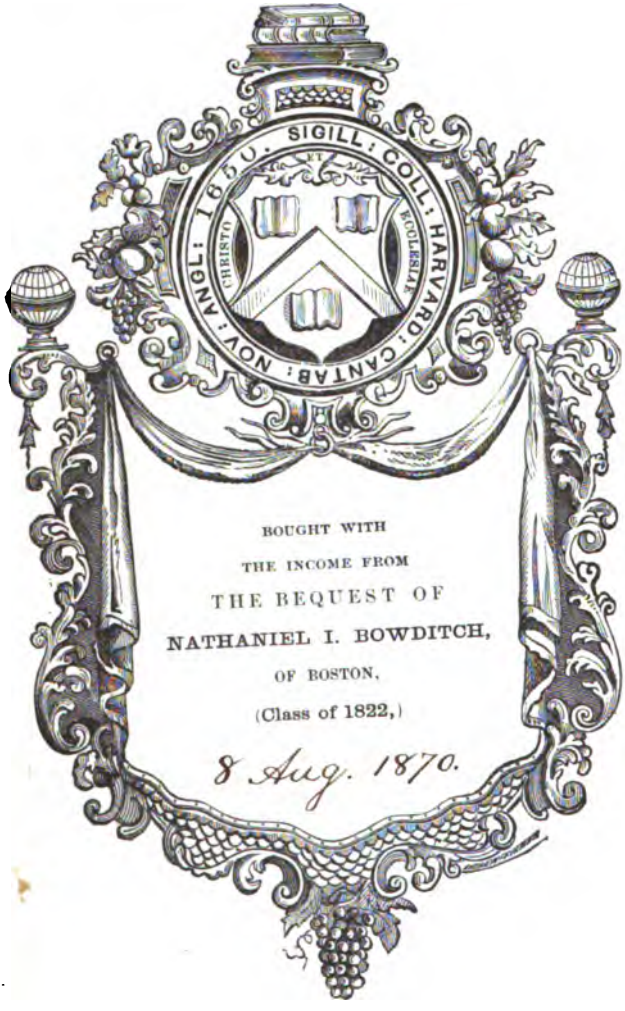

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RONALDS AND RICHARDSON'S

CHEMICAL TECHNOLOGY;

OR,

CHEMISTRY IN ITS APPLICATIONS

TO THE

Arts and Manufactures.

NEW EDITION.

VOL. I.—PART I.

Anal. 1,2.

CHEMICAL TECHNOLOGY;

OR,

CHEMISTRY IN ITS APPLICATIONS

TO THE

Arts and Manufactures.

BY

DR. EDMUND RONALDS,

PROFESSOR OF CHEMISTRY IN QUEEN'S COLLEGE, GALWAY;

AND

DR. THOMAS RICHARDSON,

OF NEWCASTLE-ON-TYNE.

WITH WHICH IS INCORPORATED

A REVISION OF DR. KNAPP'S "TECHNOLOGY."

ILLUSTRATED WITH FOUR HUNDRED AND THIRTY-THREE ENGRAVINGS ON WOOD, AND TWO COLOURED AND FOUR PLAIN PLATES.

Second Edition.

VOL. I.—PART I.

Fuel.

FUEL AND ITS APPLICATIONS.

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PREFACE.

DURING the few years which have elapsed since the publication of the first volume of our edition of Dr. Knapp's "Chemical Technology," so rapid has been the growth and so great the development of those branches of manufacture more intimately connected with fuel, that, in preparing a Second Edition, we have found it necessary not only to re-write much of the original, but to extend so considerably the limits of the first group as to occupy the entire of this volume, which may therefore with far greater propriety be called a new work than a second edition.

The elaborate researches undertaken at the instigation of the Governments of the United States and of this country into the chemical nature of coal, more particularly with reference to its adaptation to the generation of steam, and the recent legislative measures towards the prevention of smoke in cities, have invested this subject with unusual interest, while its importance is placed in a most striking light by the following statement of the annual quantities of coal raised in this and other countries, which we have compiled from the works and reports of Messrs. Hall, Taylor, and Sullivan.

I. Great Britain.

	Tons.
Household	19,000,000
Iron Works	13,000,000
Steam, Gas, Coking, &c.	9,000,000
Export	400,000
	45,000,000
Scotland	7,500,000
Ireland	220,000
Total tons	52,720,000

Or from Inspectors' Reports.

Northumberland and Durham	13,300,000
Cumberland	1,000,000
Lancashire and North Wales	10,000,000
Staffordshire, Shropshire, and Worcestershire	8,000,000
Yorkshire, Derbyshire, &c.	7,000,000
South Wales	10,000,000
Scotland	7,500,000
Ireland	220,000
Total tons	57,020,000

II. Other Countries.

United States	6,250,000
Belgium	6,250,000
France	5,000,000
Russia	5,000,000
Austria	810,000
Spain	1,000,000
	24,310,000

which cannot be estimated at less than £20,000,000; or more than equal in value to any of the metals produced, except gold, as shown by Whitney's table in the Appendix.

Improvements unceasingly roll on in the industrial application of fuel; and Mr. Wilson's description of the processes at Belmont is true of all: "Our manufacture never stands still, so that if you were to describe the work to-day, it would require correction six months hence." It is, therefore, a source of great gratification to refer to two branches of manufacture which, even in their beginnings, have acquired a national importance, and are full of promise for the future.

The first is Mr. Young's discovery of the economical production of paraffine oil by the slow distillation of coal, which has already affected the price of sperm oil at least 25 per cent, and produced a substitute during a reduction of 50 per cent in the importations. The trade in sperm oil is almost entirely in the hands of our noble competitors the Americans, and we refer to some interesting information on this subject in our Appendix, which will indicate the marvellous change this one discovery is destined to accomplish, by superseding the hazardous pursuit in the Southern Ocean.

The second is the remarkable growth of the fat acid manufacture, which cannot be better illustrated than by the circumstance that the Belmont Candle Company, while producing *twenty tons* of candles *daily*, found it necessary to *double* their manufacturing power, and for this purpose lately erected new works near Liverpool, the roof of which covers $3\frac{3}{4}$ acres. The number of people employed by this single firm will now be about two thousand.

The washing machines of Berard and Du Meynier, the production of paraffine in such quantities at Bathgate, and the recent observation that wood naphtha may be obtained by distilling coal with heated steam, wonderfully increase the value of our fossil fuel, and almost tempt us to anticipate the period when from

within our borders we shall be able to supply all the materials for warming, heating, illuminating, lubricating, and cleansing, which the increasing civilisation of the nation may demand.

While enlarging the scope of the work, we have been careful to retain its peculiar feature,—the arrangement of the subject into groups, comprising those branches of manufacture which are dependent upon each other, and necessarily connected in a commercial point of view. Thus, among the products obtained from the dry distillation of fuel will be found an account of the manufacture of pyroligneous acid and its salts, of ammonia and its salts, of coal-tar naphtha, &c., which were not included in the first edition.

The application of fuel has also been much more fully discussed in this edition; and for the illustration of this section we have largely availed ourselves of Peclet's work, "Sur la Chaleur et ses Applications," as also of Scheerer's "Metallurgie."

Our pages contain a description of the various furnaces in which fuel is consumed, but we are still without a simple method for preventing the formation of smoke, which shall be universally applicable and easily worked. The requirements of the recent Act of Parliament, and the premium offered by the Steam Coal Collieries Association at Newcastle-upon-Tyne, will, we hope, stimulate the inventive spirit of our country to accomplish this desirable object.

While the manufacture and purification of gas have been vigorously pursued since the publication of our first edition,—of which no more striking proof can be furnished than in the employment of oxide of iron as a purifier, and the increased durability of clay-retorts, which, from lasting only eighteen

months or two years, are now, as in the case of those manufactured by Mr. Cowen, of Blaydon Burn, sound and good in the fifth year,—we have not yet the pleasure to record the application of any unobjectionable plan for removing the bisulphuret of carbon from gas, nor have the valuable constituents of coal-tar yet been fully worked up into a merchantable form.

The enterprising undertaking in Ireland for converting her immense resources of Peat into some available form, though not attended with the prosperity expected, nor such as it deserves, will at all events prove the pioneer of future success. The valuable application of charcoal, lately suggested by Dr. Stenhouse,—its use as an absorbent in agriculture,—the novel method of working up refuse and small charcoal in France,—and the wide field for the employment of paraffine, encourage the hope that the labours of Mr. Reece and his friends may yet prove highly remunerative.

We have added a chapter on the question, What is Coal? on the reply to which, important interests depended in the recent causes of "Gillespie *v.* Russel," in Scotland, and "Gesner *v.* Cairns," in New Brunswick. The question has attracted great attention from Mr. Quekett and several distinguished philosophers in this country, who have examined these minerals with the aid of the microscope, and we have been fortunate in obtaining Dr. Aitken's assistance in this inquiry.

The greater number of the Analytical Tables at the end of the volume were compiled by Mr. R. C. Taylor for his extensive work on the "Statistics of Coal," to which we have added all the analyses made known since the publication of that work.

We have now the pleasing duty to acknowledge our obligations

to Mr. T. J. Taylor, of Earsden, for the valuable information he supplied, which will be found in the section on the Safety-lamp; which chapter has been kindly revised by Mr. N. Wood, President of the Northern Mining Institute, and Mr. Clarke, of Wallsend.

Our thanks are equally due to Mr. Jukes, Director of the Geological Survey of Ireland, who so promptly responded to our invitation to answer the question, What is Coal?, in a geological point of view. Mr. Reid, of Pelton, in the same manner also replied to this query as a miner. The most laborious contribution in this section comes from our friend Dr. Aitken, now at the seat of war, who made upwards of forty drawings, from which we have selected those beautiful illustrations that adorn this volume by the liberality of our publisher. We have also, lastly, to thank Mr. Quekett, of London, who has obligingly examined the whole chapter.

Mr. Wilson, of Belmont, whose time is necessarily so occupied with the gigantic establishment over which he presides, was also equally courteous, and our chapter on the manufacture of candles has had the benefit of his able correction.

We are also indebted to the kindness of Mr. Robert Stephenson for the illustrations of the furnaces of the locomotive and marine engines, as well as the important information on the consumption of fuel in the former.

Mr. Sullivan, of Dublin, kindly supplied most of the information on the manufacture of the products from Peat; and the valuable assistance of Mr. Binney, of Manchester, and Mr. Hurst, agent for Messrs. Young and Co., have enabled us to present the importance of the manufacture of paraffine oil in a striking light by the statistics embodied in our Appendix.

In the article on Coal-gas, our friends have furnished the most varied information. Mr. Thompson's papers in the "Journal of Gas-lighting" are a mine of knowledge on this subject. Mr. Wright, of Westminster, has been most liberal in his contributions, while the whole has had the benefit of Mr. Barlow's revision.

Lastly, we beg to thank all those gentlemen who have so kindly responded to our queries touching the special processes of manufacture, as also the following, who very liberally provided specimens of coal for microscopical and chemical examination:—Messrs. Adams, of Newport; Carr, of Seghill; Clarke, of Wallsend; Cowen, of Blaydon; Dickenson, of Manchester; Mackworth, of Bristol; Peace, of Wigan; Reid, of Pelton; Ritchie, of Belfast; Reeks, of the Museum of Economic Geology; Smith, of Halifax, N.S.; Sopwith, of Allenheads; and N. Wood, of Hetton.

August, 1855.

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CHEMICAL TECHNOLOGY;

OR,

CHEMISTRY APPLIED TO THE ARTS

AND

MANUFACTURES.

GROUP I.

THE BRANCHES OF MANUFACTURE CONNECTED WITH THE PRODUCTION OF FUEL AND THE PROCESS OF COMBUSTION.

EVERY person who has directed his attention to the necessary conditions for carrying on any branch of manufacturing industry, will have learnt at the outset that heat and the powerful effects produced by its agency, take precedence of all others. It is impossible to name any manufacture in which either an elevated temperature or the power obtained by means of that temperature, are not employed in some part of the process. Even agriculture, the most backward of all the arts, is gradually substituting steam power for performing those operations in which manual dexterity has hitherto been employed; and small steam-engines are springing up on every farm of consequence in the North of England and Scotland, which will no doubt increase in number with a knowledge of scientific principles and the necessity for saving labour in that all-important art, and in a few years, the production of corn and beasts, in short of food generally, will

stand as much in need of artificial heat as the economical production of cotton fabrics, iron, or any of the chemical or metallurgical products of our island.

These latter departments of industry, however, are entirely dependent upon the agency of heat, and, generally speaking, of an intense heat. It is therefore of importance to every one connected with these arts, to acquire a knowledge of the sources of heat, and the chemical and physical laws concerned in its production, so as to apply this invaluable agent in the manner best suited to the object in view and with the greatest amount of profit and economy.

Every substance possessing the property of burning in the air, that is of combining with its oxygen with the evolution of light and heat, might be employed as a heating agent, but of the numerous combustible bodies which nature supplies, few are found in sufficient quantity to be generally applicable to the production of artificial heat. These few, however, are so abundant and so generally diffused, that no inhabited country is entirely devoid of one or other of them; indeed, so essential is artificial heat, in some form or other, to human existence, that no country totally without the means of producing it, would be habitable for any length of time.

The wealth and manufacturing ascendancy of this country depend in a great measure on the abundant supply of one of the richest sources of artificial heat lying buried in the earth, in her coal-fields. England had but small influence in the councils of Europe until these were discovered and turned to full account by the indomitable industry and enterprise of her inhabitants; and without so invaluable an accessory to the acquirement of wealth and power, her commercial fate and fame might soon have sunk to a level with those of Venice or of Holland.

FUEL.

The substances to which allusion has been made above, and which we collectively call *Fuel,* are: 1. wood; 2. peat or turf; 3. brown-coal or lignite; 4. pit-coal or coal; 5. wood-charcoal; 6. peat-charcoal; 7. coke from brown-coal and coal, certain combustible gases, and artificial fuel.

The first four are natural productions, and the others are obtained from them by important manufacturing processes.

The whole of these substances are more or less closely allied to wood or woody fibre, from which they have all originally been derived, and all are indebted for their combustible properties to the carbon and hydrogen of which they are essentially composed.

These two elements, together with oxygen and small quantities of nitrogen, water and inorganic salts (ash) compose the entire mass of the natural fuels; and their relative value depends in a great measure upon the proportions in which the two former elements enter into their composition.

Most of the artificial fuels contain carbon as the essential ingredient; the other elements, with the exception of the ash, having been expelled in the processes of manufacture.

The value of fuel is diminished by the ash, which is not combustible; and the sulphur and phosphorus sometimes present are peculiarly prejudicial in some of its applications.

The facility with which fuel is ignited and continues to burn, depends much upon its chemical constitution and the porosity of its texture. A large amount of hydrogen is generally favourable to rapid ignition; this element separates, in combination with a portion of carbon, as carburetted hydrogen, at a temperature below redness, and surrounds the remainder of the fuel with an atmosphere of combustible gas in full ignition, which causes the combustion to spread. The portion of carbon which is not burnt in the form of gaseous carbo-hydrogen, is left by the escape of the gas in such a very porous state, that atmospheric oxygen easily obtains access, and the whole is consumed.

The property of burning with flame is thus intimately connected with the presence of hydrogen in the combustible, and the artificial fuels which contain no hydrogen, only produce flame when an insufficient quantity of air is directly supplied to them for the production of carbonic acid, carbonic oxide is then generated, which may again be ignited in contact with more air.

Wood, peat and some kinds of brown and gas coals produce the longest flame; they contain the largest amount of hydrogen, and are most easily decomposed. Coal is not generally so inflammable, and some varieties, as anthracite, burn without flame, like charcoal and the other artificial fuels. These distinctions are important in many applications of fuel. Where the materials to be heated are separated from the combustible, an inflammable fuel must be selected, the greatest heat being then found at the extremity of

the flame; great local intensity of heat is obtained, so to speak, on the other hand, in immediate contact with those kinds of fuel which are consumed without flame.

WOOD.

The trunk, roots, and larger branches of trees are all called *wood*. The other parts, leaves, twigs and small branches, called *brushwood*, are likewise used as fuel, and differ from the more solid portions in the proportions of the several constituents to be mentioned hereafter, and in the inflammability and heating power which they exhibit; but as these form a very small proportion of the wood employed as fuel, it is unnecessary to specify these differences more minutely than is done in the subsequent table, showing the elementary composition and amount of ash in some of the more important.

Wood is composed of three different substances: first, *woody fibre*, a combination of carbon, hydrogen, and oxygen, which forms the cells and vessels of the plant, and makes up the chief part of its bulk; second, the *constituents of the sap* contained in the vessels; and last, *water*. Recently felled wood necessarily contains all three constituents. The two first only are supporters of combustion, and produce heat; the water, on the contrary, whilst the wood is burning, is converted into vapour at the expense of a portion of the heat. As woody fibre and water are common to all kinds of wood, the difference which has been shown to exist between different woods must entirely depend upon the constituents of their sap, and upon their structure (density). Notwithstanding the great difference, chemically speaking, in the constituents of the sap, (the coniferous woods containing resinous matter; the beech and birch, extractive; and the oak, tannin); the accurate analysis of dried woods has shown that they contain the three elementary constituents, *carbon*, *hydrogen*, and *oxygen*, nearly in the same proportions as pure woody fibre, so that the constituents of the sap must form a very small proportion of the whole bulk of the wood, and their action cannot materially alter the value of the wood as fuel, although it becomes very perceptible when the wood is applied to certain practical purposes, as in the process of tanning. The amount of water in wood has greater influence, and is of much more importance, as it materially influences its calorific power. Water is generally most abundant in wood at the time of the flow of the sap, and least,

when the growth is less rapid; for which reason, wood should always be felled at the latter stage, unless the important secondary uses for which it is sometimes cultivated, as for the tannin in the bark, &c., render it desirable to fell it at an earlier stage of growth. The amount of water (sap) in wood differs according to the time of year at which it is felled. Thus, Schübler and Neuffer found in:

Woods.	Water. At the end of January.	At the beginning of April.
Ash	28.8	38.6
Sycamore . .	33.6	40.3
Horse-chesnut	40.2	47.1
White Fir . .	52.7	61.0

It is also greater in the young shoots and twigs than in the more solid stem, and varies also in amount in woods of a like nature but of different botanical species, as the following table (given also by Schübler and Neuffer) shows.

100 Parts of fresh cut wood from the

	Water.		Water.
Hornbeam (*Carpinus betulus*) contain	18.6	Pine (*Pinus sylvestris L.*) contain	39.7
Willow (*Salix caprea*) . .	26.0	Red Beech (*Fagus sylvatica*) .	39.7
Sycamore (*Acer pseudoplatanus*)	27.0	Alder (*Betula alnus*) . .	41.6
Mountain Ash (*Sorbus aucuparia*)	28.3	Aspen (*Populus tremula*) .	43.7
Ash (*Fraxinus excelsior*) .	28.7	Elm (*Ulmus campestris*) .	44.5
Birch (*Betula alba*) . .	30.8	Red Fir (*Pinus picea dur.*) .	45.2
Wild service tree (*Crataegus tormin.*)	32.3	Lime Tree (*Tilia europæa*) .	47.1
Oak (*Quercus robur*) . .	34.7	Italian Poplar (*Populus italica*)	48.2
Pedicle Oak (*Quercus pedunculata*)	35.4	Larch (*Pinus larix*) . .	48.6
White Fir (*Pinus abies dur.*) .	37.1	White Poplar (*Populus alba*)	50.6
Horse-chesnut (*Aesculus hippocast.*)	38.2	Black Poplar (*Populus nigra*)	51.8

Chevandier examined the hygroscopic state of beech-, oak-, white beech-, birch-, aspen-, alder-, willow-, fir-, and pine-wood, from different parts of the same tree and at intervals of one-half, one year, one-and-a-half, and two years, after the trees had been felled. The numerous specimens upon which he experimented, amounting to 181 in number, were taken from trees of various ages, having grown upon different soils, and the specimens were exposed to the free access of air in an open shed, protected, however, from the rain and the direct action of the sun's rays. The amount of moisture in each was determined at the different intervals by drying weighed quantities, in the form of sawdust, at a temperature of 140° C. (284° F.) *in vacuo*, until they ceased to lose weight.

From these experiments it appeared that the soil and site upon

which the trees grew exerted no appreciable influence upon the amount of moisture contained in or retained by the wood.

The minimum of hygrometric water in the woods, or the maximum state of dryness, was attained for the greater number after the lapse of a year and a half; the others required two years to be brought to the same state.

The resinous woods dry more rapidly, but likewise absorb moisture with greater avidity, than those which contain no resin; and among the latter, the softer kinds (birch, aspen, alder, willow) contain more water in the fresh state than the harder woods; they lose this water, however, with greater ease, and can be more thoroughly dried.

The following mean results were obtained from the experiments:

1. MEAN QUANTITY OF HYGROMETRIC WATER CONTAINED IN THE RESINOUS WOODS.

Trunk-wood . . .	half a year after felling . .	29 per cent.
Brushwood . . .	„ „ „ . . .	32 „
Young branch-wood	„ „ „ . . .	38 „
Trunk-wood . .	in the driest state	15 „
Brushwood . . .	„ „ „	15 „
Young branch-wood	„ „ „	15 „

2. MEAN QUANTITY OF HYGROMETRIC WATER CONTAINED IN THE NON-RESINOUS WOODS.

Trunk-wood . . .	half a year after felling . .	26 per cent.
Brushwood . . .	„ „ „ . . .	34 „
Young branch-wood	„ „ „ . . .	36 „
Trunk-wood . . .	in the driest state	17 „
Brushwood . . .	„ „ „	20 „
Young branch-wood	„ „ „	19 „

These numbers must be viewed as minima, single specimens being more perfectly dried than wood stacked and not freely exposed to the air.

In recently felled wood, therefore, from $\frac{1}{3}$ to $\frac{1}{2}$ of its weight is water, and in that commonly used for fuel about $\frac{1}{5}$. This quantity is very much diminished by keeping the wood dry and exposed to the air, but it is not entirely removed under any circumstances.

After the expiration of one and a half or two years, when the wood is in the driest state to which it can be brought by exposure, the hygroscopic properties of the air and the wood appear to be in a state of equilibrium and to balance each other, the amount of water in the latter varying within narrow limits with the season of the year and with the hygrometric state of the atmosphere at the time of observation. In this state of dryness, in which wood is best adapted for use as fuel, the wood is said to be *air dried.* The remaining moisture can only be expelled with the aid of heat, and the last portions with such difficulty that the wood commences at the same time to decompose, and becomes brown.

Rumford heated the following air-dried woods at a temperature of 277° F. as long as they lost weight, without being chemically changed, and found that 100 parts of

Oak-wood lost . .	16.64	Fir-wood lost . .	17.53
Elm „ „ . .	18.20	Birch „ „ . .	19.38
Beech „ „ . .	18.56	Lime „ „ . .	18.79
Maple „ „ . .	18.63	Poplar „ „ . .	19.55*

For practical purposes, such a complete state of dryness can seldom be attained, and the wood used for fuel, after exposure to the air for 10 or 12 months, contains from 20 to 25 per cent of water. The former number taken as the mean, reduces 100 lbs. of air-dried wood to only 80 lbs. of real fuel. Wood, several years old, which had been kept in a warm room for six months, still retained about 17 per cent of water (Winkler.†)

Wood is commonly divided into the *hard* and *soft* kinds, a distinction grounded upon the facility with which it is worked, and upon its power of producing heat. The former class, embracing the wood of the oak, white and red beech, birch, elm and alder, contains in an equal bulk more solid fibre, the vessels are narrower and more closely packed than in that of the softer kind, which includes the wood of the pine, fir, white fir, larch, lime, willow, and poplar. High situations, much exposed to wind, and a poor soil, cause the annual rings to be less developed, and

* The same kinds of wood, freed in like manner from water at a temperature of 277° F. and exposed in shavings to the air, absorbed in winter (at 45° F.) from 17—19 per cent, and in summer (at 62° F.) from 6—9 per cent of water within 24 hours, which facts easily explain why wood is dried with so much difficulty.

† The wood composing the beam of a room 150 years old and preserved from moisture, had a spec. grav. 0.682 and contained 10.5 per cent water.

consequently more closely packed than is the case with wood which is protected and growing on the more fruitful soil of valleys. The specific weight of wood must necessarily stand in a certain relation to its hardness, and increase with the latter, and this being a point of some practical importance, several experimenters have turned their attention to the subject. The specific gravity of wood, which is the sum of the weight of the solid matter with that of the water contained in it, and of the air of the pores,* cannot be ascertained with that degree of accuracy to which we are accustomed in scientific investigations, as these different constituents occur in variable proportions.

The difficulty of arriving at a knowledge of the true specific gravity of wood has been very much increased by the different, and often inaccurate, modes of experimenting which have been adopted for determining this point. Wood, supposing it free from pores containing air, is sensibly heavier than water. Thus, after destroying the pores by rasping and determining the volume of the raspings, the specific gravity of lime-wood was found to be 1.13, of fir-wood 1.16, of oak-wood 1.27, of beech-wood 1.29. Rumford's experiments led to the conclusion that the solid part of all woods without distinction had a specific gravity of about 1.5. Experience has shown that wood sinks after long immersion in water, when the air has been expelled from it.

The specific gravity of wood has been observed to vary in the same variety, with the age of the specimen, the nature of the soil upon which it has been grown, the climate, &c.; it is not even the same in different parts of the same tree. Young wood is specifically heavier than old, and heart-wood bears a like relation to sap-wood.

In the following table the respective weights of the different kinds of wood, in the state in which they are used as fuel, are given according to the best authorities.

* Thus Rumford calculated from the specific gravity of the fresh wood of sappy trees, and from that of its solid parts, that 1 cub. ft. of fresh oak-wood contained 390 cub. in. of solid fibre, 360 cub. in. of sap, and 240 cub. in. of enclosed air. Poplar-wood in the same state contains in the cubic foot, 243 cub. in. of fibre, 219 cub. in. of sap, and 538 cub. in. of air; lime-wood, 265 cub. in. of wood, 365 cub. in. of sap, and 370 cub. in. of air. According to another calculation, 1 cub. ft. of air-dried lime-wood contains 558 cub. in. of air in the pores; fir-wood, 586 cub. in.; oak-wood, 481 cub. in.; and beech-wood, 457 cub. in.

SPECIFIC GRAVITY OF DIFFERENT KINDS OF WOOD; WATER BEING UNITY.

Variety of Wood.	I. Recently felled.	II. Dried in air.	III. Strongly dried.	IV. Strongly dried.	V.
Common Oak (*Quercus robur*)	1.0754	0.7075	0.6441	0.663	0.929
Pedicle Oak (*Quercus pedunculata*)	1.0494	0.6777	—	0.663	—
White Willow (*Salix alba*)	0.9859	0.4873	0.4464	0.457	0.585
Beech (*Fagus sylvatica*)	0.9822	0.5907	0.5422	0.560	0.852
Elm (*Ulmus campestris*)	0.9476	0.5474	0.5788	0.518	0.600
Hornbeam (*Carpinus betulus*)	0.9452	0.7695	—	0.691	—
Larch (*Pinus larix*)	0.9205	0.4735	—	0.441	—
Scotch Fir (*Pinus sylvestris*)	0.9121	0.5502	0.4205	0.485	—
Sycamore (*Acer pseudoplatanus*)	0.9036	0.6592	0.5779	0.618	0.755
Ash (*Fraxinus excelsior*)	0.9036	0.6440	0.6137	0.619	0.734
Birch (*Betula alba*)	0.9012	0.6274	0.5699	0.598	—
Mountain Ash (*Sorbus aucuparia*)	0.8993	0.6440	—	0.552	—
Fir (*Pinus abies, Duroi*)	0.8941	0.5550	0.4303	0.493	0.550
Silver Fir (*Pinus picea, Dur.*)	0.8699	0.4716	0.3838	0.434	—
Wild service (*Cratægus torminalis*)	0.8633	0.5910	—	0.549	0.874
Horse-chesnut (*Aesculus hippoc.*)	0.8614	0.5749	—	—	—
Alder (*Betula alnus*)	0.8571	0.5001	—	0.443	0.800
Lime (*Tilia europæa*)	0.8170	0.4390	0.3480	0.431	0.604
Black Poplar (*Populus nigra*)	0.7795	0.3656	—	0.346	0.383
Aspen (*Populus tremula*)	0.7654	0.4302	—	0.418	—
Italian Poplar (*Populus italica*)	0.7634	0.3931	0.4402	—	—
Ground Willow (*Salix caprea*)	0.7155	0.5289	—	0.501	—
Guaiacum Wood	Grif-	1.3420	—	—	—
Ebony	fith.	1.2260	—	—	—

The columns I. and II. contain the weights ascertained by Hartig; and column III. the less accurate determination of Wernek. The specimens of wood employed by the latter were dried in an oven until they ceased to lose weight, and the loss which they sustained, on being immersed in water, was then determined. In the IVth column, the results obtained by Winkler are given, who weighed an exact cubic inch of each wood. The specimens had been kept for six months in a strongly heated chamber, and the water they contained had been thus reduced to an average quantity of 9 per cent. The Vth column contains Mushenbroek's numbers. A very extensive list of the relative weights of the woods from different countries will be found in the Reports of the Juries of the Exhibition of 1851.

The following recent determinations of the specific gravity of woods were made by Karmarsh:

Names of Woods.	SPECIFIC GRAVITY.				Mean weight of 1 cub. foot of air-dried wood in lbs.*
	In the green state.		In the air-dried state.		
	Limits.	Mean.	Limits.	Mean.	
Maple	0.843—0.944	0.893	0.645—0.750	0.697	37 lbs.
Apple	0.960—1.137	1.048	0.734—0.793	0.763	41 „
Birch	0.851—0.987	0.919	0.688—0.738	0.713	38 „
Pear	. . . . .	. .	0.646—0.732	0.689	37 „
Red Beech	0.852—1.109	0.980	0.690—0.852	0.771	41 „
Box	. . . . .	. .	0.912—1.031	0.971	52 „
Cedar	. . . . .	. .	0.561—0.575	0.568	30 „
Ebony	. . . . .	. .	1.187—1.331	1.259	67 „
Oak	0.885—1.062	0.973	0.650—0.920	0.785	42 „
Alder	0.809—0.994	0.901	0.505—0.680	0.592	31 „
Ash	0.778—0.927	0.852	0.540—0.845	0.692	37 „
Pine	0.848—0.993	0.920	0.454—0.481	0.467	25 „
Scotch Fir	0.811—1.005	0.908			
Larch	0.694—0.924	0.809	0.565	0.565	30 „
Lime	0.710—0.878	0.794	0.559—0.604	0.581	31 „
Poplar	0.758—0.956	0.857	0.383—0.591	0.487	26 „
Guaiac	. . . . .	. .	1.263—1.342	1.302	69 „
Silver Fir	0.894	0.894	0.498—0.746	0.622	33 „
Elm	0.878—0.941	0.909	0.568—0.671	0.619	33 „
Willow	0.838—0.855	0.846	0.392—0.530	0.461	25 „
White Beech	0.939—1.137	1.038	0.728—0.790	0.759	40 „

Most trustworthy results, obtained by the method of immersion, have been recorded by Marcus Bull, who took the precaution of covering each specimen with a varnish of specific gravity = 1.000, which, without giving rise to error, ensured the presence of the whole natural quantity of air in the wood. The most important of his experiments are given in the table below; they apply only to foreign woods.

Walnut (with scaly bark)	1.000
White Oak (chesnut?)	0.885
American Ash	0.772
Beech	0.724
Hornbeam	0.720
Wild Apple	0.697
Sassafras	0.618
Virginian Cherry	0.597
American Elm	0.580
Virginian Cedar	0.565
Yellow Pine	0.551
Birch (poplar-leaved)	0.530

* The Hanoverian pound is equal to 1.031114 lb. English.

American Horse-chesnut	0.522
Italian Poplar	0.397

The European woods, as shown in the table at page 10, are therefore rather less than one half lighter than water, and a cubic foot weighs from 26 to 42 lbs. Wood dried in the air decreases in bulk, often as much as 0.1 of the whole.

A numerous series of experiments by Marcus Bull have proved that in an ordinary stack or pile of American wood, there is contained, for every 56 parts of actual wood 44 parts of unoccupied space. This fact, in conjunction with the experiments upon the specific gravity of different woods given in the table at page 10, led to the following actual quantity of wood in either given compass:

	Pounds avoirdupois in a cubic meter. (35.3 cubic feet English.)	Pounds avoirdupois in a cubic foot.
Walnut (with scaly bark)	1227.6	34.7
White Oak (chesnut?)	1075.8	30.5
American Ash	919.4	26.0
Beech	880.0	24.9
Hornbeam	875.6	24.8
American Elm	704.0	19.9
Yellow Pine	668.0	18.9
Birch (poplar-leaved)	647.6	18.3
American Horse-chesnut	633.6	17.9
Italian Poplar	481.8	13.6

As wood that has been 12 months felled still contains about 25 per cent of water, the foregoing numbers must be multiplied by $\frac{3}{4}$ in order to yield the true amount of perfectly dry wood.

In mountainous districts, where the wooded parts are steep and intersected with rapid streams, the latter are frequently made subservient in transporting wood for fuel. In the Black Forest, in the neighbourhood of Salzburg, and in other places, large quantities of wood are floated down the rivers in this manner; but when this practice is more carefully looked into, it appears that the advantage of cheap transport is partly counterbalanced by the inferior quality of the wood so transported. Long immersion in water necessarily dissolves out all the soluble matters, and thus diminishes the volume of the wood, as well as its power of

producing heat. Wernek asserts, that 1 cubic foot of wood may lose 1 lb. of its weight by being floated.

When wood is burnt, it always leaves an incombustible residue, or ash; this residue consists of earthy and alkaline salts, which the living plant takes up from the soil, and which are essential to its healthy development.

This ash consists of lime, potash, soda, oxide of iron, oxide of manganese and silica, in combination with carbonic acid, chlorine, sulphur, sulphuric acid, phosphorus or phosphoric acid. Many of the bases in the sap are in combination with organic acids, and these salts become carbonates on incineration. The greater part of the ash, indeed, is composed of the carbonates of lime and of the alkalies. The silica appears to exist in an uncombined state in the juices of the plant, and the sulphur and phosphorus must be traced to the albuminous constituents of the latter.

The composition of the ashes of various trees and plants will be found under the section on potash.

The amount of ash varies with the kind of wood, and is likewise different in the several parts of the same tree and in trees of different age. The soil upon which the trees are grown has also some influence upon the quantity and nature of the ash.

In some varieties of wood the ash does not exceed ½ per cent, while others contain from 2 to 5 per cent.

The following results were obtained by Berthier and Karsten from the incineration of the several varieties of wood:

Amount of ash in 100 parts.

Varieties of Wood.	I. BERTHIER.	II. KARSTEN.	
		In young wood.	In old wood.
Silver Fir (*Pinus picea*) . .	0.83	0.15	0.15
Birch	1.0	0.25	0.30
Scotch Fir (*Pinus sylvestris*)	1.24	0.12	0.15
Oak	2.50	0.15	0.11
Lime	5.00	0.40	—
Fir (*Pinus abies*)	—	0.23	0.25
White Beech	—	0.32	0.35
Alder	—	0.35	0.40
Red Beech	—	0.38	0.40

Berthier's results were obtained with air-dried wood.

The most recent researches upon this subject are those of Chevandier, and the following are the mean quantities of ash which he found in several experiments with some of the woods that are used as fuel, and which were all previously thoroughly air-dried (containing therefore about 20 per cent of water):

Ash in 100 parts of:

	Solid stem-wood.	Wood of branches.	Brush-wood.
Beech . . .	0.73	1.54	0.72
Oak . . .	1.94	1.49	1.32
Birch . . .	0.57	1.00	0.48
Aspen . .	1.49	2.38	—
Willow . .	2.94	3.66	—

It has already been stated that the constituents of wood, as regards the relative proportions of their elements, do not differ much from pure woody fibre (wood purified from extractive matter and water). The knowledge of these proportions not only serves to explain the peculiar properties of the several woods, but is essential in estimating their relative values. Schödler and Petersen have furnished us with the following results derived from the elementary analysis of woods dried at 100° C., and previously pulverised:

In 100 parts they found the following relations:

Species of Wood.	Carbon.	Hydro-gen.	Oxy-gen.	Species of Wood.	Carbon.	Hydro-gen.	Oxy-gen.
Pure woody fibre .	52.65	5.25	42.10	Populus nigra . . .	49.70	6.31	43.99
Quercus robur . .	49.43	6.07	44.50	Tilia europæa . .	49.41	6.86	43.73
Fraxinus excelsior.	49.36	6.075	44.57	Salix fragilis . .	48.44	6.36	44.80
Acer campestris .	49.80	6.31	43.89	Pinus abies . . .	49.95	6.41	43.65
Fagus sylvatica .	48.53	6.30	45.17	Pinus picea . . .	49.59	6.38	44.02
Betula alba . . .	48.60	6.375	45.02	Pinus sylvestris .	49.94	6.25	43.81
Ulmus campestris .	50.19	6.425	43.39	Pinus larix . . .	50.11	6.31	43.58

The following determinations of the elementary composition of some European woods have been lately made with great care by Chevandier.*

The specimens were dried at 140° C. (284° F.)

* Ann. de Chim. et de Phys. 3 ser. X, 129.

ELEMENTARY COMPOSITION OF SOLID WOOD, AFTER DEDUCTING THE ASH.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	
Beech	49.89	6.07	43.11	0.93	mean of 7 analyses.
Oak	50.64	6.03	42.05	1.28	„ „ 5 „
Birch	50.61	6.23	42.04	1.12	„ „ 4 „
Aspen	50.31	6.32	42.39	0.98	„ „ 3 „
Willow	51.75	6.19	41.08	0.98	„ „ 2 „

ELEMENTARY COMPOSITION OF BRUSHWOOD AND BRANCHES, AFTER DEDUCTING THE ASH.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	
Beech	51.08	6.23	41.61	1.08	mean of 4 analyses.
Oak	50.89	6.16	41.94	1.01	„ „ 4 „
Birch	51.93	6.31	40.69	1.07	„ „ 3 „
Aspen	51.02	6.28	41.65	1.05	„ „ 2 „
Willow	54.03	6.56	37.93	1.48	„ „ 2 „

The composition of different woods does not vary so much as might have been anticipated, yet while hydrogen and oxygen are contained in woody fibre in the same proportions as those in which they unite to form water, (1 : 8), this relative proportion is not accurately observed in the different woods, the hydrogen being always contained in them in larger and in variable quantity.

As a general result, however, ordinary air-dried wood may be viewed as composed of:

20 per cent hygroscopic water,
40 „ oxygen and hydrogen in the proportions in which they unite to form water,
40 „ charcoal, including 1 per cent of ash.

Heated from 120° to 140° C. (248°—284° F.) the wood loses its hygroscopic water and becomes *kiln-dried,* and then contains:

50 per cent of oxygen and hydrogen in the proportions in which they combine to form water,
50 „ charcoal, containing 1 per cent of ash.

The wood is chemically changed when heated more strongly, as will be described under the head of charcoal.

TURF OR PEAT.

When a district is spread out in the form of a flat basin of greater or smaller dimensions, and the water which collects upon its surface or rises from springs, cannot freely escape, but stagnates for a length of time, forming a shallow lake, as is not uncommon in the temperate zones, particularly where evaporation goes on slowly and the atmosphere is habitually moist, as for instance, in Ireland, then water-plants of all kinds, sedges, rushes, reeds, algæ, mosses, more especially *Sphagnum*, even shrubby plants, as willows, &c., spread from the sides towards the centre of the pool, and quickly form a thick covering of vegetation. With the change of season these plants die and fall to the ground, making room for a second crop in the following spring; this process goes on from year to year, until the shallow pool becomes a bog, and is at length completely filled up with a loose spongy vegetable mass. The remains of the plants immersed in water quickly decay; they lose their original solidity with the simultaneous evolution of gas (marsh gas, carbonic acid) and a disagreeable and noxious smell, while oxygen at the same time is absorbed from the atmosphere and from compounds, such as sulphates, contained in the soil and the water surrounding them, which are reduced to the state of sulphurets. The vegetable matters become brown and soft, and are eventually converted into a black-coloured, soap-like mass. The debris of plants reduced to this state by decay, or in which the process is still going on, is called *turf* or *peat*.

Such is now almost universally acknowledged to be the natural process by which peat has been produced, and the older hypotheses, that it is a formation as old as the hills and valleys where it occurs; a bituminous deposit from the sea; the wreck of once floating islands; or an actually growing vegetable substance, may be viewed as entirely exploded.

The plants from which turf seems to have been principally formed in the northern hemisphere are the mosses, amongst which *Sphagnum palustre* chiefly predominates. Besides these, heath and fern, rushes and reeds are frequent, and one or more species of cotton-grass (*Eriophorum*) are also common. Whole trees, oaks, firs, ash, birch, yew and willow, have been frequently found at the bottoms of peat bogs, sometimes erect, as if they had been gradually buried by the encroaching growths of moss, in which

they have ultimately perished, at others lying prostrate, in which position they may have aided in impeding the flow of water and in accelerating the growth of the bog. Human remains have been dug up in turf bogs, sometimes in a state of high preservation, although bearing upon them, in the form of hair clothes and antique sandals, clear intimations of a very long submersion and testifying to the powerful preservative or antiseptic qualities of the turf. Remains of animals now extinct, and fatty substances known as bog-butter, and consisting principally, according to Mr. Brazier, of an acid which he calls *butyro-limnodic acid* ($C_{32}H_{32}O_4$),* support the foregoing statements.

In the southern hemisphere, according to Darwin, peat does not occur nearer the equator than the 45th degree of latitude, and the peat there formed is composed of the remains of almost all the plants growing in the vicinity, including the grasses; it is remarkable, however, that no mosses appear to have taken part in the formation of South American peat, which is chiefly composed of the remains of a plant called by Brown *Astelia pumila*.

Small deposits of turf are found in almost every country, but districts of immense extent occur upon the low shores of the North Sea and German Ocean (Holland and North Germany), in the formation of some of which, the waters of the sea appear to have borne a part.

In mountainous districts the hollows are frequently filled with peat bogs, the constant assemblage of clouds upon the mountains favouring their growth by a gradual but incessant supply of moisture. These bogs, however, are seldom very extensive, nor does the deposit generally exceed 6 feet in thickness. In Holland entire districts are covered by this formation; in Ireland one-seventh of the whole island, or an area of 2,830,000 acres, consists of peat-moor; and in France, the great marsh of Montoire, near the mouth of the Loire, is said by Blavier to be more than 50 leagues in circumference.

These vast growths of peat are deep in proportion to their extent, the moors of Holland averaging 2 fathoms, while those of Ireland are often 30 feet in depth.

Sometimes the peat formation appears to have taken place at successive periods; the layers are then generally separated by deposits of sand. Although peat sometimes comes quite to the surface, it is frequently covered with sand or mould, but is always found in horizontal layers of moderate thickness. Peat belongs to

* Chem. Gaz. Oct. 1st, 1852.

the more extensively diffused kinds of fossil fuel, and may be distinguished into two kinds, differing in geological age, and in the amount of decomposition to which they have been subject. They are :

1. *Recent peat,* in which the structure of the roots and stems of vegetables is still perfect, and which possesses a very porous, specifically light texture, is soft and exceedingly fragile. Passing from a light to a blackish-brown colour, and containing the roots and fibres which are really foreign to it, disseminated through an earthy matrix, it gradually verges, without any marked distinction, into the

2. *Older peat,* in which all organic structure has disappeared, and the fibrous has given place to an earthy texture. Those kinds of peat are considered the oldest, in which the structure has become so fine in the grain, so free from fibre, and so dense, as to appear, when freshly cut, as smooth and shining as wax or pitch. All varieties of peat belonging to this class are distinctly heavier than those belonging to the former; while a cubic foot of the more porous kind only weighs about 4 lbs., the weight of a cubic foot of the latter amounts to from 12 to 20 times as much (Karmarsh).*

The humic acid contained in peat, and observed by Sprengel, as also the various other products of the decomposition of woody fibre, which constitute its chief mass, are of little interest, as regards its application. The same may be said of the resins discovered in it by Mulder, and described by him.

Peat is cut and prepared for use in a very simple manner. In Ireland, Germany, and most other parts, the surface of the deposit is laid bare by removing the sod or earth above it, and the peat is cut with common spades, or with the slade, an instrument resembling a long spade, with a portion of the blade turned up at right-angles on the one side, into the shape of thick bricks, which are placed to dry, piled up loosely one against the other, or upon

* The grand-duchy of Hesse comprises extensive peat-moors. The Rhine, formerly obstructed in its course at Bingen, was forced to spend its waters over the low-lands opposite Mayence, and the stagnating water which remained after the Rhine had forced its passage through the rocks at Bingen gave rise, in the still swampy district called Ried, to the formation of peat, which is now cut at Pfüngstadt and Griesheim. The peat of the latter locality is dense, heavy and black, and closely related to the older peat; that of the former is light, without earthy constituents, rich in the roots of plants, of a light colour, and evidently belongs to the more recent species. The quality of the Griesheim peat is very superior to that from the other locality.

some kind of support. Care is taken to separate the peat of the upper part of the layer, which is young and fibrous, from the heavy and more plentiful lower peat.

The process adopted in Holland is somewhat more circuitous, but certainly more appropriate, which exactly resembles the preparation of bricks by moulding. The peat is scooped with spades as long as practicable, and when the peaty mass, which is more spongy than solid, becomes too thin to be thus advantageously collected, a particular kind of instrument is substituted for the scoop commonly used upon such occasions. This consists of a kind of sharpened iron ring fixed upon a handle, forming as it were, the side of the scoop; the ring is perforated with small holes on every side, and serves as a support for the bottom, which is formed of a net or piece of cloth. This instrument prevents any quantity of water being scooped up with the peat, the holes allowing the water to run off immediately. The peat-mud collected in this manner is converted into a homogeneous mass by treading with the feet and stirring about with rakes like mortar; the stones are picked out, and it is then spread out evenly in layers of one foot in thickness in large wooden boxes, such as are used for slaking lime, that the water may run off and the mass become dry. To facilitate this, and prevent the adhesion of earthy matter, the bottom of the box is previously covered with hay. After some days, when the mass exhibits a certain consistence, it is subjected to another operation, in which women and children are employed, who, instead of beating it, strap flat boards, like snow-shoes, to their feet, and stamp upon it in all directions. The treading is continued until no impression is produced by a common foot-step; and the peat is lastly struck with beaters until the surface is uniform. The whole cake, eight or nine inches in thickness, is divided by means of long laths into squares of about four inches across. The thickness of the cake corresponds with the length of the bricks. To effect the complete desiccation, the first brick taken out is laid transversely upon the second, the third is laid upon the fourth, and so on; this order is afterwards reversed when the pieces are piled.

In some places, the peat-mud is scooped out with buckets to a dry place, and the water being allowed to drain away, it is made into bricks with moulds. Too much water in the peat may completely destroy its value and render it incapable of being piled.

The value of peat is in proportion to its dryness, density, and firmness. If it possess these qualities in a slight degree only,

it suffers by carriage and by keeping, the upper layers of the heap compressing and breaking the lower layers, which are thus rendered valueless. The porosity and brittleness of peat prevent its application in all cases where the fuel and other matters to be heated are piled up to any considerable height one upon the other.

Dense peat comprises, in *an equal bulk*, much more combustible matter than porous peat. This fact has led, in recent times, particularly in Ireland, to the construction of presses for the purpose of improving the quality of the lighter kinds of peat, but the difficulty of introducing a machine which is at once rapid in its action, cheap, and effective, has not yet been entirely overcome, the elasticity of the fibre offering great obstacles to the action of the press. It is evident that the use of a press, in addition to the advantages named, would also very much aid the drying process. In one experiment, a brick weighing 8 lbs. lost 2.5 lbs. of water under the press.

Where a large demand admits of peat being prepared upon a manufacturing scale for consumption, the process introduced by Mr. C. M. Williams at Cappoge, in Ireland, has been employed, but we fear without much profit. It consists in breaking up the fibre of freshly-cut turf, placing it thus broken between cloths, and submitting it to the action of a powerful hydraulic press. The peat on leaving the press occupies only $\frac{1}{8}$ of its previous volume, and has lost about $\frac{7}{8}$ of its weight from the water which has been expelled. It is then denser than wood, although prepared from the lightest varieties of peat, and is said to have no tendency to reabsorb water. The cost of the process is not considerable, as the prepared peat can be delivered at 5*s.* per ton; the price of the unprepared material in the neighbourhood of the moors being 3*s.* 6*d.* per ton.

The longer peat is kept and allowed to dry in suitable sheds, the more it will improve as a heating agent. The spongy character of peat enables it to retain a large but very variable quantity of hygroscopic water. Karsten observed a loss of as much as 45 per cent by simply drying freshly-cut peat in the air, but even when thus dried the quantity of moisture retained varied between 25 and 50 per cent, which could be driven off at a higher temperature. The specimens examined were however probably in the latter case not fully dried, and in this state the peat is principally consumed in this country and in Ireland, creating as it must a loss of heat equivalent to 30 per cent. Under

any circumstances peat dried in the air retains, in virtue of its porous structure, a larger proportion of water than wood under the same conditions. Thoroughly dried under cover, it is said to contain $\frac{1}{10}$ of its weight of water. Ronalds found from 86 to 90 per cent of water in freshly-cut peat, and from 53 to 56 in that dried in a room for several months, while peat dried in the open air only contained 30 per cent of moisture. Messrs. Kane and Sullivan found from 10 to 24 per cent of moisture in air-dried turf.*

Another constituent, which is of little consequence in wood, is sometimes so abundant in peat as to render it quite useless; this is the ash, which is derived from two sources: first, the quantity of ash peculiar to the vegetable bodies from which it has been produced, inasmuch as this has not been dissolved out by the bog-water; and second, the earthy matter which has been collected during the deposition of the peat. Peat-ash is essentially different in quality from the ash of wood, and varies in quantity to a much greater extent. Thus, in 100 parts of dry peat, the following quantities of ash have been observed.

Variety of Peat.	Ash.	Observer.
Grass Peat, brownish-yellow	1 — 1.5	Karmarsh.
Pitch Peat	1.2 — 8	
Young, dark brown	to 5 to 7	
Old earthy Peat	10	
Black, firm, from Neumünster	2.2	Suersen.
„ „ Sindelfingen	7.2	Schübler.
Brown, loose, from Schwenningen	2.3	
Very old Peat, from Vulcaire, near Abbeville	5.58	Regnault.
„ „ Long „	4.61	
Not so old, from Champ de feu „	5.35	
Near Berlin, 1. Stage	9.3	Achard.
„ 2. „	10.2	
„ 3. „	11.2	
Black, old, from Möglin	14.4	Einhof.
Brown, young	14.3	
Moor, in Eichsfeld, 1. sort	21.5	Buchholz.
„ „ 2. „	23.0	
„ „ 3. „	30.5	
„ „ 4. „	33.0	
In 41 sorts, from the Erzgebirge	1 — 24	Winkler.
In 3 varieties from Holland and Friesland	4.61—5.58	Mulder.
In 27 varieties from the central bog of Allen, in Ireland	1.120—7.898 mean 2.62	Kane and Sullivan.
In 3 varieties from the neighbourhood of Tuam in the west of Ireland	3.695—4.819 mean 4.545	Ronalds.
In 9 varieties from Schnaditzer bog, near Schwemsal, in Saxony	5.30—37.10 mean 18.47	Wellner.

* "Report on the Nature and Products of the Process of the Destructive Distillation of Peat," made to the Chief Commissioner of Woods, by Messrs. Kane & Sullivan, 1851.

Peat may, therefore, contain from 1 per cent to ½ of its weight of ash. Carbonates of the alkalies are said never to be found in this ash; phosphates and especially sulphates are abundant, the former being in the form of phosphate of lime. Einhof found 15.25 lime, 20.5 alumina, 5.5 oxide of iron, 41 silica, 15 phosphate of lime, 1.55 common salt and gypsum, in 100 parts of ash; Schübler even found 34 per cent of phosphates in the ash of peat from Schwenningen, to the presence of which its chief value as a manure is ascribed.

The ash of the three specimens analysed by Ronalds and noticed in the table at page 20, was composed as follows:

	I.	II.	III.
Potash	0.813	3.558	5.189
Soda	3.666	0.370	0.758
Lime	35.854	34.790	36.599
Magnesia	3.170	3.601	7.727
Alumina	4.423	2.801	3.440
Peroxide of Iron . .	2.565	6.345	6.499
Chlorine	4.327	0.432	0.596
Sulphuric Acid . .	12.860	19.703	16.463
Phosphoric Acid . .	2.194	3.567	2.816
Carbonic Acid . . .	3.254	6.764	7.169
Silica soluble in Acid.	4.744	3.337	4.898
Insoluble Matter . .	22.920	12.919	6.811
	100.790	98.187	98.965

I. Light peat from Ballinderry bog, taken at 4½ feet from surface. Bog 15 feet deep.

II. Somewhat older peat from Claretuam bog, taken 3½ feet from surface. Bog 16 feet deep.

III. Light peat from Wood Quay or Weirs' bog, taken 4½ feet from surface. Bog 22 feet deep.

The composition of the ashes of peat from the central bogs of Ireland has been examined in 27 specimens by Kane and Sullivan, the details of which may be found in their report before alluded to. We subjoin their results.

COMPOSITION OF THE ASHES OF DIFFERENT PEATS.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
Specific Gravity	0.397	0.405	0.669	0.450	0.351	0.661	0.335	0.476	0.655	0.484	0.984	0.681	0.523	0.247
Potash	0.362	1.323	0.461	0.401	0.221	0.198	0.491	0.211	0.247	0.641	0.347	0.181	0.291	0.966
Soda	1.427	1.902	1.399	1.330	0.712	0.590	1.670	0.651	0.496	1.875	0.679	0.550	0.586	1.038
Lime	26.113	36.496	40.920	37.873	33.240	25.860	33.037	29.716	24.944	22.702	45.581	29.323	38.692	35.113
Magnesia	3.392	7.634	1.611	5.137	1.904	1.207	7.523	1.204	1.285	6.809	1.256	3.425	2.373	4.687
Alumina	4.180	5.411	3.793	0.271	0.240	0.371	1.686	0.298	0.360	1.109	0.129	0.672	0.408	1.697
Peroxide of Iron	11.591	15.608	15.969	14.802	12.760	18.746	13.281	20.372	19.405	29.854	15.974	19.095	15.537	14.322
Phosphoric Acid	1.461	2.571	1.406	1.257	1.222	0.874	1.438	1.066	0.242	2.019	0.188	0.975	0.878	0.828
Sulphuric Acid	12.403	14.092	14.507	11.814	21.470	23.630	20.076	22.664	10.742	16.881	44.371	16.238	14.822	25.409
Hydrochloric Acid	1.568	1.482	0.983	1.367	0.840	0.622	1·747	0.439	0.335	1.591	0.337	0.636	0.657	1.090
Silica in Compounds decomposable by Acids	0.980	3.595	1.111	1.002	1.672	0.896	3.148	0.645	1.083	0.737	1.043	3.255	5.808	5.607
Sand and Silicates undecomposable by Acids	22.519	2.168	2.107	4.722	13.147	14.430	7.683	11.180	26.789	14.505	2.653	8.884	14.181	4.340
Carbonic Acid	13.695	7.761	15.040	19.722*	12.060	12.240	8.340	10.782	13.890	1.470	16.120	15.984	5.842	5.003
Total	99.691	100.043	99.307	99.688	99.488	99.654	99.120	99.228	98.817	99.693	99.678	99.218	100.074	100.080

	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	XXIII.	XXIV.	XXV.	XXVI.	XXVII.
Specific Gravity	0.394	0.437	0.323	0.924	1.058	0.481	0.629	0.280	0.546	0.855	0.402	0.441	0.858
Potash	0.407	0.665	0.668	0.280	0.744	1.667	.271	0.146	0.247	0.219	0.370	0.028	0.158
Soda	2.074	2.606	1.709	2.180	0.704	2.823	1.491	0.466	1.150	0.855	2.628	2.833	0.527
Lime	33.397	33.554	31.553	30.744	40.623	20.907	13.667	8.492	22.332	40.079	27.732	26.551	12.432
Magnesia	11.293	9.229	9.439	9.237	4.362	15.252	16.994	4.702	5.608	4.035	6.875	12.580	3.095
Alumina	1.627	0.677	1.707	2.027	1.671	2.034	0.259	10.705	0.932	0.895	1.521	3.298	5.991
Peroxide of Iron	18.500	18.366	6.012	19.797	10.368	17.040	26.644	15.052	29.970	14.160	7.451	12.116	30.725
Phosphoric Acid	0.744	1.300	1.286	1.290	1.114	1.447	1.339	1.557	0.699	0.633	1.670	2.022	0.526
Sulphuric Acid	13.550	23.505	25.602	20.857	24.208	23.375	23.691	13.974	31.612	22.295	20.389	22.401	14.518
Hydrochloric Acid	2.804	3.263	0.698	3.128	1.052	1.424	1.180	0.196	0.993	0.781	2 932	2.581	0.151
Silica in Compounds decomposable by Acids	5.998	4.449	5.159	3.096	6.317	6.634	2.719	12.476	2.751	1.295	7 709	5.474	9.101
Sand and Silicates undecomposable by Acids	6.593	3.040	6.282	3.163	3.710	10.682	11.673	31.198	3.775	5 496	10.088	17.711	22.731
Carbonic Acid	3.006	...	9.864	3.570	4.981	6.721	...	...	...	9.101	10.460	1.220	...
Total	99.993	99.653	99.979	99.369	99.844	100.006	98.964	98.928	100.069	99.843	99.825	98.751	99.945

* The quantity of carbonic acid found by experiment is in nearly every case much less than that required to saturate the lime, supposing the whole of the sulphuric acid to exist as sulphate of lime; this is accounted for by the high temperature necessary to incinerate the peat having driven off the greater part of the CO_2.

I.—Light spongy surface-peat, reddish-brown colour, composed almost entirely of *Sphagnum*, species still distinguishable; from near Monastrevin.

II.—Light surface-peat, reddish-brown colour, containing small roots of *Erica*, and leaves of grasses and *Carex;* from Mount Lucus bog, near Phillipstown, King's County.

III. Rather dense peat, dark reddish-brown colour, structure of moss still distinguishable; from same locality as II.

IV.—Light reddish-brown fibrous moss-peat. *Sphagnum* almost unaltered, as well as leaves of *Carex* and other plants, and the roots of species of *Erica;* from Tichnevin, Kildare.

V.—Upper layer of fibrous red bog, composed entirely of *Sphagnum*, *Hypnum* and other mosses; from Derrymullen station of the Irish Amelioration Society.

VI.—Dense peat of blackish-brown colour. Vegetable structure nearly obliterated, leaves of grasses and *Carex*, and twigs of hazel and apparently of birch sometimes found. Wood of Allen, Great Timahoe bog.

VII.—Light surface-peat, pale yellowish-brown. Mass very open, grained and fibrous. *Sphagnum* and *Hypnum* readily distinguished; from Wood of Allen.

VIII.—Middle layer of same bog, deep reddish-brown colour. Mass tolerably compact, but still fibrous. Structure of the moss very indistinct. A very few roots of *Erica* and small twigs of birch and alder, and scales of fir; from Wood of Allen.

IX.—Lower layer of same bog. Compact and dense, deep blackish-brown, fracture earthy, appearing almost conchoidal, and exhibiting a resinous lustre when rubbed. All appearance of vegetable structure nearly obliterated. Wood of Allen.

X.—Good compact peat, blackish-brown colour, principally consisting of moss, with a good many roots of *Erica* and grasses, *Carex*. Used as fuel in Dublin; from Riversdale bog, near Kinnegad.

XI.—Excessively hard compact peat. Vegetable structure completely obliterated; some pieces exhibiting a perfectly resinous conchoidal fracture. Scales of fir-trees and twigs of birch, alder, &c., sometimes occur. A valuable fuel. Baltinoran and Rawson bogs, near Kinnegad.

XII.—Very dense dark reddish-brown peat. Vegetable structure only occasionally perceptible; from Anadruce and Cloncreim, on the Royal Canal.

XIII.—Rather dense peat, of a dark reddish-brown colour. Structure of *Sphagnum* very indistinct, but leaves of the flag, and stems and roots of *Erica* occur in a perfect state. Structure compact; from bogs of Rathconnel, Wood Down and Great Down, near Mullingar.

XIV.—Upper layer of fibrous bog. Mass spongy and of a yellowish-red colour. Composed of almost unaltered *Sphagnum*, with occasional roots of *Carex*, *Erica*, &c.; from neighbourhood of Banagher.

XV.—Rather compact peat, of reddish-brown colour. Vegetable structure very perceptible, but impossible to distinguish species; roots of *Erica* abundant, but greater part evidently derived from moss. Same locality as XIV.

XVI.—Still more compact peat than XV., consisting of fibrous or red bog, colour light reddish-brown. Structure of mosses still visible, but species cannot be discriminated; roots and leaves of *Carex* exceedingly abundant. Same locality as two preceding.

XVII.—Light surface-peat, of a pale reddish-brown. Mass spongy and composed of almost unaltered *Sphagnum*, with a few stems and roots of *Erica*; from the bogs of Clonfert and Kilmore, at the mouth of the River Suck, near Banagher.

XVIII.—Rather compact peat, of a light reddish-brown colour, fibrous, but passing into black peat. Structure of mosses still perceptible. Abundant remains of *Carex* and grasses; from the same locality as XVII.

XIX.—Exceedingly dense dark blackish-brown peat; fracture earthy, sometimes conchoidal. Vegetable structure almost completely destroyed, but when apparent, remains of *Carex*, grasses and *Erica* abundant; from Athlone bog.

XX.—A rather dense peat, of a blackish-brown colour, in which the structure of moss is no longer visible, but abounding in remains of *Carex*, grasses, and roots and stems of *Erica*; from Curragh or Clonbourne bogs, near Shannon Bridge.

XXI.—A dense peat, of a dark reddish-brown colour. Remains of *Carex* and grasses very abundant, but *Sphagnum* much compressed and structure very indistinct; from bogs along the Shannon. Used in steamers plying on the river.

XXII.—Light fibrous peat, of reddish-brown colour, evidently formed of a great number of plants. Structure of moss very distinct. Species of *Sphagnum* and *Hypnum* distinguishable. Remains of

Carex and grasses, with roots of *Erica*, and bark of birch, and probably alder-twigs abundant. Same locality as XXII.

XXIII.—Very dense peat, of a blackish-brown colour. Mass compact. Vegetable structure very indistinct. Remains of *Carex* abundant, and roots of *Erica* frequent. An excellent fuel. Same locality as XXII.

XXIV.—A very dense blackish-brown compact peat. Vegetable structure almost obliterated. Fracture earthy. Full of tubes of the bark of hazel, birch and alder, and occasionally scales of pine-bark, and leaves of *Carex* and grass. Same locality as XXII.

XXV.—A rather dense reddish-brown peat. Structure very indistinct. *Carex* leaves altered, and occasionally a few fragments of twigs and roots. Same locality as XXII.

XXVI. — Rather compact and moderately dense peat, of a dark reddish-brown colour. Structure of moss almost obliterated. Abundance of leaves, stalks and roots of grasses, *Carex*, &c. Same locality as XXII.

XXVII.—Dense jet-black peat. Structure of moss completely destroyed. Fracture earthy, tending to conchoidal, assuming resinous lustre when rubbed. Abundance of remains of *Carex* leaves, and a very few fragments of bark, apparently of hazel. Same locality as XXII.

Density of Peat.—The weight of peat depends upon its state of dryness, and its age. Karmarsh gives the following relative weights for different kinds of Hanoverian peat: 1. Light-coloured, young grass peat, nearly unchanged moss, 0.113 to 0.263. 2. Young brown and black peat, an earthy matrix intersected with roots, 0.240 to 0.600. 3. Old earthy peat without any fibrous texture, 0.564 to 0.902. 4. Old peat, pitch peat, 0.639 to 1.039. Moulded peat from Griesheim (near Darmstadt), of good quality, has been found to weigh 0.706, so that 1 cubic foot would weigh on an average 22 lbs. and 100 bricks (at 56 cubic inches), 123.5 lbs.* These leave after incineration a mass of ash, which although less in bulk, retains the form of the brick, and is very considerable in quantity.

Sir R. Kane estimates the specific gravity of light surface-peat at about 0.400, and from this it increases, with the compactness of

* 1000 pieces of Griesheim Peat are calculated at 74300 c. f. and weigh 1170 lbs.
" " Pfungstädt " " 75600 " " 820 "
" " " best and driest 49000 " " 660 "

the substance, to nearly the density of coal. A cubic yard weighs, packed closely in sods, about 900 lbs. The densest turf will weigh as much as 1,100 lbs. per cubic yard, while the lightest may not weigh more than 500 lbs. Compared with coal in fragments as employed in the furnace, peat is about ½ as dense. A cubic yard of coal averaging about 13 cwt.

The maximum specific gravity of peat from the series of 27 specimens of all kinds and characters from the great bogs in the centre of Ireland, as given at p. 22, by Sir R. Kane and Dr. Sullivan* to be 1.058, and the minimum 0.235; the greater number of specimens being however below 0.6.† The quantity of water contained in these specimens, after being dried in the air, ranged between 10.446 per cent in a specimen taken from the middle layer of a bog, and 33.270 per cent in a very dense compact specimen, in which vegetable structure was very indistinct. The mean quantity in the 27 specimens was 21.6.

A cubic foot of the earthy peat examined by Karmarsh gave nearly 3 lbs. of ash; a quantity which must be very prejudicial in many of its applications; partly from the dust which it makes and the space it occupies;‡ and partly by its chemical action in smelting processes, destroying the bars of grates, besides decreasing, of course, the quantity of combustible matter.

The conditions under which peat is produced should have a tendency to increase its amount of carbon above that contained in woody fibre. Regnault and Mulder have both examined the elementary composition of different varieties of peat; the following are their results, after deducting the amount of ash stated in the previous table:

Localities.	Carbon.	Hydrogen.	Oxygen.	Analysts.
Vulcaire . . .	59.57	5.96	34.47	Regnault.
	60.40	5.86	33.64	Mulder.
Long	60.06	6.21	33.73	Regnault.
	60.89	6.21	32.90	Mulder.
Champ de Feu .	60.21	6.45	33.34	Regnault.
	61.05	6.45	32.50	Mulder.
Friesland . . .	59.42	5.87	34.71	ditto.
Friesland . . .	60.41	5.87	34.02	ditto.
Holland . . .	59.27	5.41	35.32	ditto.

* "Report on the Nature and Products of the Process of the Destructive Distillation of Peat, considered especially with reference to its Employment as a Branch of Manufacturing Industry." London, 1851.

† For details of these, see Table, page 22.

‡ In a fire, which converted 320 lbs. of water into steam in 9 hours, 240 lbs. of peat were consumed. The ash of this, calculated at 20 per cent, would leave 48 lbs. daily on the hearth, and amount in the year to 175 cwt., the removal of which would be attended with much expense and trouble.

The last column includes the very small quantity of nitrogen in peat, which is recognised by the ammoniacal vapours that it produces on heating.

It would thus appear that peat differs essentially from wood in elementary composition. The former may be viewed as consisting of carbon and water in equal proportions by weight, while in the latter, the entire amount of oxygen being supposed in combination with hydrogen to form water, we have the following relative proportions in 100 parts:

Carbon . .	60
Hydrogen . .	2
Water . . .	38
	100

or an excess of 10 per cent carbon and 2 per cent hydrogen over that contained in dried wood, while the amount of water is reduced 12 per cent.

The following analyses of specimens of Irish peat have recently been made, showing also the amount of nitrogen which they contain. The ash was deducted in calculating these results so as to exhibit the actual composition of the organic matter.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	
				mean.		
Surface Peat, Phillipstown (Sp. II, p. 23)	58.694	6.971	32.883	1.4514	1.992	Kane and Sullivan.
Dense Peat, Phillipstown (Sp. III. p. 23)	60.476	6.097	32.546	0.8806	3.305	
Light surface Peat, Wood of Allen (Sp. VII, p. 23)	59.920	6.614	32.207	1.2588	2.745	
Dense Peat, Wood of Allen, (Sp. XX, p. 24)	61.022	5.771	32.400	0.8070	7.898	
Tichnevin Peat (Sp. IV, p. 23) . . .	60.102	6.723	31.288	1.8866	2.629	
Upper Shannon (Sp. XVII, p. 24). .	60.018	5.875	33.152	0.9545	2.474	
Upper Shannon (Sp. XXIV, p. 25). .	61.247	5.616	31.446	1.6904	2.976	
Kilbeggan, Westmeath	61.04	6.67	30.46		1.83	Kane.
Kilbaha, Clare	56.63	6.33	34.48		8.06	
Cappoge, Kildare	51.05	6.85	39.55		2.25	

The following may also be added to the list; in these the ash is not deducted.

Ochta, in Eastern Russia	39 084	3.788	51.088		6.04	Woskressensky.
Peat, 4½ft. from surface, Tuam, Ireland	57.207	5.655	28.949	3.067	5.122	Ronalds.
„ 3½ft. „ „ „ „	58.306	5.821	29.669	2.509	3.695	
„ 4½ft. „ „ „ „	59.550	5.502	28.414	1.715	4.819	

These results confirm generally the above remarks. It appears from the table of ash analyses, that the amount of sulphate of lime and phosphoric acid does not depend upon the position occupied by the peat in the bog, but rather upon local circumstances; that during the formation of peat the greater part of the alkali and phosphoric acid originally contained in the plants has been removed; and that the amount of silica is very small, especially in the fibrous varieties.

The proportions of carbon and hydrogen contained in different specimens of peat do not vary much, although the lower layers generally contain a little more carbon than those near the surface.

FOSSIL FUEL, OR COAL.

The steady and gradual operations of nature, at the present day, supply certain districts with a stock of fuel of no mean quality, by the constant interment of the lower kinds of vegetation in the manner already described; but in the earlier periods of the earth's history far more extensive stores of invaluable combustibles were laid up for the future use of mankind.

The most valuable of all the species of fuel is coal, and its discovery and application have been attended with increased prosperity in all those countries which are so fortunate as to possess it.

Coal is a dark-brown or black mineral, of no great degree of hardness, varying from 1.2 to 1.8 in specific gravity, which burns with a more or less brilliant flame and much smoke when ignited, and occurs in horizontal or more or less inclined layers, alternating with clay, and frequently with ironstone, chiefly in the geological formation which, from this circumstance, has been named the Carboniferous, and which takes position in the series of sedimentary deposits between the lower Silurian or primary fossiliferous formations on the one hand, and the New red sandstone on the other. Anthracite, the oldest species of coal, is also found in the most recent members of the transition formations; and brown coal, the youngest variety, occurs in the chalk.

There appears no reason to doubt the vegetable origin of coal. The gradual metamorphosis of woody fibre into coal can be traced chemically, step by step, through the various stages; upright fossil trees, with their roots resting in seams of coal, testify to their growth upon the site in which they remain carbonized, while

modern transformations of forests into peat-bogs, in which the trees remain erect, afford the strongest analogical evidence of the manner in which many of the ancient coal-fields may have been produced. Botanists who have paid particular attention to the fossil flora of these deposits are generally agreed in ascribing them to the accumulation and gradual decomposition of ferns, some of which were arborescent, and to vegetable forms belonging to *Calamites, Lepidodendra, Sigillariæ* and *Stigmariæ;* palms, though rare, are sometimes found; and altogether there have been found not less than from 200 to 300 species of plants.

The character and habits of these plants would indicate that a very different temperature and climate, and indeed an altogether different distribution of land and sea must have existed at the time of their growth and subsequent interment. They belong to a vegetation which is known especially to flourish in an extremely moist, warm and equable climate, with the absence of any severe cold, under circumstances and meteorological conditions, therefore, which are very different from those which characterise the coal districts of the present day. A tropical climate was at one time considered essential to the growth of these vegetable forms, and a very large excess of carbonic acid in the atmosphere above that contained at this present time has been assumed in explanation of their gigantic development. Although closely allied to tropical plants, those of the coal formation are still so distinct, that the former assumption does not appear necessary, indeed the flora of the southern coasts of New Zealand, situated in the 46th degree of latitude, is stated to bear the strongest resemblance to that of the coal formations.

From considerations of this kind it has been reasonably inferred that, at the time of the carbonaceous deposits, the northern hemisphere was pervaded by a great ocean interspersed with numerous islands of small dimensions, bearing insular or submarine volcanoes, a combination of geographical circumstances not unfavourable to the growth of a flora like that from which these deposits have been formed. Alternate elevations of sea and land, islands springing up by volcanic agency from the bottom of the ocean, might cause the waters to overflow and submerge the less elevated lands, and bury with them the forests and vegetation under layers of mud and sand. A series of such alternate changes can readily be conceived to account for the various coal deposits.

By some it has been supposed that the coal-fields resulted

from collections of drifted timber deposited in the deltas of rivers at the time of their overflow. This supposition is supported by the fact, that many of the large rivers of North America, particularly those which flow from south to north, are known to tear up and carry away, on the breaking up of the ice, numbers of large trees, which, having been completely soaked by long immersion in water, become heavy and sink, and are gradually buried in the deltas under mud, sand, and the debris of rocks, or are drifted by the currents of the ocean to more remote and quiet localities, there to undergo the process of carbonization. Heat and moisture, with the partial access of atmospheric air, appear to have been the active agents in carbonizing the buried vegetation, assisted at a later period by immense superincumbent pressure in consolidating it.

Coal is met with in more recent geological formations than the one to which it has given its name. The deposits therefore differ considerably in age, and two distinct species of coal may easily be distinguished, as well by their physical as chemical peculiarities. All coal that occurs above the chalk, is of comparatively more recent origin; the process of decay is less advanced, and it is evidently much more allied to wood, than that which lies below the chalk. The former is called *brown coal*, or *lignite*, while many varieties of the latter are classed together under the common name of *bituminous* or *pit-coal*; that variety in which the carbonization is most complete being called *anthracite*. While the entire structure of the wood is retained almost unchanged in the first, it has disappeared completely in the last two, with the exception of a few rare impressions of plants. All the varieties may be viewed as derived from woody fibre, the carbon of which for the greater part has remained, while the other elements have gradually diminished and disappeared in proportion to the age of the formation, until in the last product, *anthracite*, hardly anything but carbon is left. This is the result of a process which can be distinctly traced, by comparing the elementary composition of the different members of the series. The composition of woody fibre in 100 parts, as given at page 18, nearly corresponds with the following atomic relations of the elements:

Wood . . . . . = 36 C + 22 H + 22 O,
Take from these 3 equivs.
of carbonic acid . . = 3 C + 6 O

33 C + 22 H + 16 O

and from the remainder
1 equiv. of hydrogen . = 1 H

and we obtain the formula 33 C + 21 H + 16 O, representing exactly the composition of the brown coal of Laubach.* In a similar manner the composition of the brown coal of Ringkuhl, near Cassel, may be explained; if from the wood

= 36 C + 22 H + 22 O

we deduct 4 equivs. of carbonic acid . . . . = 4 C + 8 O

32 C + 22 H + 14 O

5 equivs. of water . . . = 5 H + 5 O

32 C + 17 H + 9 O

and 2 equivs. of hydrogen = 2 H

there will remain 32 C + 15 H + 9 O = brown coal from Ringkuhl. In both cases the same kinds of combinations are formed, only in different proportions. In the formation of coal, other products occur; thus, 24 C + 13 H + O expresses very closely the relation of the atoms in the splint coal of Newcastle, and its formation is explained by deducting the following compounds from the elements of wood.

Wood . . . . . = 36 C + 22 H + 22 O
9 equivs. of carbonic acid . = 9 C + 18 O

27 C + 22 H + 4 O

3 equivs. of water . . . = 3 H + 3 O

27 C + 19 H + 1 O

3 equivs. of carburetted hydrogen . . . . . = 3 C + 6 H

24 C + 13 H + O = splint coal.

The principal feature in the progressive decomposition of buried wood, is the production of carbonic acid from the elements of

* The analysis of this coal and of the following will be found at a subsequent page.

the wood. In the case of the formation of brown coal, when atmospheric oxygen is not so completely excluded, this element combines also with a portion of the hydrogen, which does not occur in the formation of coal. In the latter case the elements of woody fibre are simply resolved into the four products: carbonic acid, water, light carburetted hydrogen and coal. In the former, the mouldering process is predominant, but decay (eremacausis) also performs its part; the formation of coal, on the contrary, is exclusively a mouldering process. It is more than probable, that the carbonic acid accompanying the mineral waters of the carboniferous deposits, is produced at the same time as the light carburetted hydrogen, which has been observed to constitute the chief mass of the fire-damp of coal-mines. In a similar manner, the formation of all the varieties of coal may be explained; it is, however, hardly necessary to mention, that the foregoing formulæ are merely introduced for illustration, and are only true as regards the actual *atomic relations* of the individual elements.

Coal is met with in three distinct geological formations; commencing with the lowest, we find it:

1. In the *coal measures*, which may be subdivided into the older *transition series* (anthracite), and the younger *coal*.

2. In *secondary formations*, both in the older members of the new red sandstone (*Keuper* of the Germans), in the limestones of the oolite group which constitute the Jura, and in the more recent *chalk*.

3. In *tertiary deposits*, as fresh-water limestone, shell limestone, &c., with *brown coal*.

Brown Coal, or Lignite.—The coal of the tertiary formations is not always uniform in appearance. In some kinds the vegetable remains are so well preserved, their structure so distinctly retained, even the more tender parts, as leaves and fruit, so little altered, that a botanical diagnosis of the antediluvian plants has been undertaken with success. They consist of flattened stems, crossing each other in all directions, of a more or less dark colour, soft and mellow in consistence when freshly quarried, but becoming brittle by exposure, the fracture following the direction of the fibre of the wood. This variety is known by the name of *lignite, fossil* and improperly bituminous *wood*. Bovey coal (from Devonshire), the coal of the Wetterau (Salzhausen, Laubach) in Germany belong to this class (it is also called, from its texture, *fibrous*

brown coal). Other kinds present only occasional distinct indications of vegetable structure, and appear throughout as a stratified mass, of a dark, nearly black colour, possess an earthy fracture, and are called *earthy brown coal;* to this class the coal of Meissner, near Cassel, belongs; while those varieties in which the fracture is conchoidal and the structure more dense have been distinguished as *conchoidal brown coal* or *pitch coal.* Lignite is often mixed with these, and both kinds are often present in the same specimen. Although sometimes occurring at the surface, these fuels are usually obtained from a considerable depth. Fresh from the pit they are impregnated with water, which evaporates upon exposure to the air, the amount of evaporation depending upon their degree of porosity and the temperature. Reinsch found lignite from the Bavarian Upper Pfalz, to contain 43, and earthy brown coal, from the same locality, to contain 80 per cent of water. The amount of moisture in brown coal is however, generally, greater; at least Varrentrapp found that fresh coal, from Helmstedt and Schöningen, contained 48 per cent of water. After being completely dried (when a great reduction of volume occurred) these coals re-absorbed 8 per cent of moisture. Coal of this kind, kept for some time piled up, contained 29 per cent of water; after exposure to the air in summer, 20; and in a warm room after four weeks, 8 per cent. The amount of ash in brown coal itself is not very large; it is, however, frequently increased to an injurious extent by the infiltration of water containing salts, and by an admixture of earthy matter, as will be seen from the following table.

	Variety of Brown Coal, or Lignite.	Ash.	Observer.
Bohemian.	Lignite from Aussig	5.35%	Balling.
	„ „	5.51	
	„ Hegendorf	6.93	
	„ Neuendorf	5.13	
	„ Coulang	1.50	
	Earthy from Grünlas	6.66	
Bavarian Ob.-Pfalz.	„ „ Verau	10.00	Reinsch.
	Lignite „ „	3.40	
	„ Greece	9.02	Regnault.
	„ Usnach	2.19	
	„ Cologne	5.49	
	Earthy brown coal from Dax	4.99	
	„ „ „ Bouches du Rhône	13.43	
	„ „ „ Nieder-Alpen	3.01	

Variety of Brown Coal, or Lignite.			Ash.	Observer.
Cassel.	Earthy (*Stangen*) coal	Meissner.	15.47	
	„ (*Pitch*) coal		2.43	
	„ „ from Hirschberg	Ringkuhl.	0.81	Kühnert.
	Pitch coal „ „		2.76	
	Middle sort „ „		3.20	
	Lowest sort „ „		4.92	
	Pitch coal from Habichtswald		1.33	
	„ „ „		3.33	
	Stillberger coal (Söhrwald)		6.95	
	Lignite from Hirschberg		1.29	
From Duren, on the left bank of the Rhine.	„ Iceland		8.8	Karsten.
	„ „ (another specimen)		27.5	
	„ Utweiler		0.9	
	„ Grube Urwelt		4.6	
	„ „ „		27.05	
	„ Friesdorf		1.69	
	„ „		14.9	
Near Bonn, on the right bank of the Rhine.	„ Putzchen		4.4	
	„ „		17.4	
	„ Stösschen		14.4	
	„ „		28.2	
	„ Orsberg		43.2	
	„ „		58.0	
	Coal from Schöningen	Brunswick	7.8	Varrentrapp.
	„ Helmstädt		8.4	
	Slate coal from Azberg		4.5	Reinsch.
	„ „ Aga Reuss		6.0	
	Earthy Lignite from Wigan		4.95	J. A. Phillips.
	„ „ Conception Bay		7.49	Admiralty Coal Investigation.
	Lignite from Sandy Bay, Patagonia		13.29	
	„ „ Talcahnano Bay		6.92	
	„ „ Artern, Germany		1.16	Kremers.

The amount of ash, even in the same deposit and in different parts of the same piece, varies more than is the case with peat; which may be seen from Karsten's experiments. The general conclusion to be drawn from these results is therefore, that the amount of ash in brown coal varies from 1 to 50 per cent. In most cases, however, it is not less than 5, and seldom above 10 per cent. Reinsch found in the ash of lignite, from Verau:

Sulphate of Lime	3.6
Hyposulphate of Potash . .	1.9
Hyposulphite of Lime . . .	25.4
Protosulphate of Iron . . .	50.
Sand	20.
	100.9

The ash of earthy brown coal yielded:

Sulphate of Lime	3.
Hyposulphite of Lime . . .	7.
Protosulphate of Iron . . .	57.
Sand	33.
	100.

Varrentrapp found in the ash of brown coal from Brunswick:

Sulphate of Lime	57.5
Magnesia	2.58
Alumina	11.57
Oxide of Iron	5.78
Carbonate of Potash . . .	2.64
Silica and Clay	19.27
	99.34

Brown coal, such as that of Orsberg, consisting of one half mineral matter, cannot be considered fuel, but can be made use of for other purposes (see Alum). In addition to the ash and the elements of wood, brown coal contains from 0.5 to 1.5 per cent of nitrogen, which has not been separately estimated in the following analyses.

Brown Coal contains (in addition to the Ash), see page 34.	Carbon.	Hydrogen.	Oxygen. Nitrogen.	Observer.
Earthy, from Dax . . .	69.52	5.59	19.90	Regnault.
„ Bouches du Rhône . .	63.01	4.58	18.98	
„ Nieder-Alpen . .	69.05	5.20	22.74	
Earthy, consisting of stems from Meissner .	70.12	3.19	7.59	Kühnert.
„ Pitch coal „ „ „ .	56.60	4.75	27.15	
„ „ from Ringkuhl, Hirschberg	60.83	4.36	24.64	
„ „ „ Habichtswald .	57.26	4.52	26.10	
„ lustrous coal, Ringkuhl . .	66.11	4.82	18.51	
„ allied to Pitch coal, Habichtswald .	54.18	4.20	26.98	
„ lowest vein, at Ringkuhl . .	52.98	4.09	21.91	
„ middle „ „ . .	54.96	4.01	22.31	
„ Stillberger . . .	50.78	4.62	21.38	
„ Helmstädt, Prince William mine .	68.57	4.84	19.87	Varrentrapp.
„ „ another mine . .	67.88	6.85	17.46	
„ Schöningen, Treue mine . .	63.71	5.07	22.79	
„ „ another pit . .	64.80	4.54	23.12	
Lignite, from Ringkühl . . .	51.70	5.25	30.37	Kühnert.
„ Greece . . .	60.36	5.00	25.62	Regnault.
„ Cologne . . .	63.42	4.98	27.11	
„ Usnach . . .	55.27	5.70	36.84	
„ Laubach . . .	57.28	6.03	36.10	Liebig.
Earthy brown coal, from Wigan . .	80.21	6.30	8.54	J. A. Phillips.
„ „ „ Conception Bay .	70.33	5.84	16.34	Admiralty Coal Investigation.
Lignite from Sandy Bay, Patagonia . .	62.19	5.08	19.44	
„ Talcahnano Bay . .	70.71	6.44	16.93	

The actual organic portion of brown coal in its different modifications according to the analyses of Regnault is therefore as follows:

	Locality.	Character.	Carbon.	Hydrogen.	Oxygen & Nitrogen.
Lignite, fossil wood or fibrous brown coal.	Greece . .	Laminated, black, with indications of organic structure .	66.36	5.49	28.15
	Cologne .	Ligneous texture, friable, brownish-red in powder .	66.04	5.27	28.69
	Usnach . .	Fossil wood, woody texture, very hard	56.50	5.83	37.67
Earthy brown Coal, or perfect Lignite (Regnault.)	Dax . . .	Fine black, irregular fracture, no ligneous texture . .	73.18	5.88	21.14
	Bouches du Rhône .	Slaty, black and brilliant, no ligneous texture . . .	72.78	5.29	21.93
	Mont Meisner . .	Brilliant, conchoidal fracture .	72.00	4.93	23.07
	Basses Alpes . .	Black, fatty lustre . .	71.20	5.36	23.44
Pitch Coal, conchoidal brown coal or lignite passing into bitumen.	Ellnbogen .	Compact, homogeneous, fracture conchoidal . . .	76.58	7.85	15.57
	Cuba . .	Black, like velvet, fatty lustre.	77.88	7.55	14.57

The mean of these experiments after deducting the ash would lead to the following general composition for the organic portion of the varieties of brown coal:

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Fibrous brown Coal .	63	5	32
Earthy „ „ .	72	5	23
Pitch „ „ .	77	7.5	15.5

The whole of the oxygen being supposed combined with hydrogen to form water, the composition would then be nearly as follows:

	Carbon.	Hydrogen.	Water.
Fibrous brown Coal .	63	1	36
Earthy „ „ .	72	2	26
Pitch „ „ .	77	5.5	17.5

The weight of air-dried brown coal varies within narrow limits; the specific gravity of the specimens of lignite examined by Regnault varied from 1.100 to 1.85, of the earthy coal from 1.254 to 1.276. Kühnert found the latter to vary from 1.310 to 1.436, whilst lignite had a specific gravity of 1.279, and the lignites examined by the officers of the Admiralty Coal Investigation varied from 1.291 to 1.321. A cubic foot of brown coal will therefore weigh on an average 80 lbs., but the absence of uniformity in the nature of the substance hardly admits of applying to a larger quantity the weights obtained from experiments upon

a small scale. The numbers found, clearly show that the variations are independent of the amount of ash.*

MINERAL OR PIT COAL.

The use of fossil fuel, which exerts so powerful an influence upon the history of modern times, is, even in England, a result of the scarcity of wood, and by no means very ancient.

The ninth century is named by some authors as the period of the discovery of coal in England. In 1239 King Henry III. granted to the good men of Newcastle the privilege of digging coals, but it is not more than two hundred and fifty years since coal came into general use as a fuel in London, and at that period two ships were sufficient for carrying on the whole trade. A proclamation in the reign of Edward I., and another in the time of Elizabeth, prohibited the use of stone coal in London during the sitting of Parliament, lest the health of the knights of the shire should suffer during their residence in the metropolis; and shortly before 1649, the citizens of London are stated to have petitioned Parliament against two nuisances or offensive commodities which were likely to come into great use and esteem, and these were, "Newcastle coals, on account of their stench, &c., and hops, in regard they would spoyle the taste of drinck, and endanger the people."

Newcastle coal was first introduced in Paris in 1520. In Scotland the privilege of digging coal was granted to a religious house in 1291. In Belgium the earliest reference to mineral coal was in 1198 or 1200 in the county of Liege, where tradition ascribes its application as a fuel to a blacksmith.†

According to Marco Polo, the Chinese were acquainted with coal as a fuel at a very early period.‡

Coal is very much more abundant in the carboniferous and secondary, than in the tertiary formations; the deposits in the two former being, individually, much more extensive. It occurs in beds, or seams, sometimes called veins, interstratified with

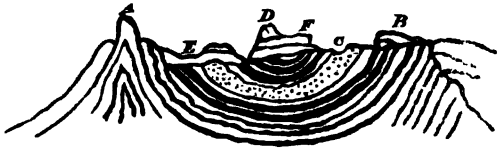
* In the grand-duchy of Hesse brown coal has been found at the following places: 1 in Upper Hesse, near Lauterbach or Zell, at Laubach (Hessenbrücken), Salzhausen, Friedberg (Dorheim, Bauernheim), Eberstadt, Obererlenbach, Grünberg (Zeche Buderus). 2. In the province Starkenburg, near Seligenstadt.

† "History of Fossil Fuel."

‡ "In the mountains of Cataja," as this distinguished traveller relates, "a kind of black stone is dug up, which laid upon the fire burns like wood, and when once ignited continues to burn for a long time, so that, if placed upon the fire in the evening, it will burn during the whole night. The stone when first ignited produces a small flame, like charcoal; it then continues to glow and gives off much heat."

numerous other minerals, filling up what appear to have been hollows, or valleys, at the time of its deposition, and have frequently received the appellation of *coal-basins*. The separate layers of coal and other minerals generally come to the surface, or *crop out* at the sides of these basins, defining thus the entire outward area of the formation. The accompanying cut, Fig. 1, represents one of the basins belonging to the Somersetshire and South Gloucestershire coal-fields. The elevations at *A* and *B*

FIG. 1.

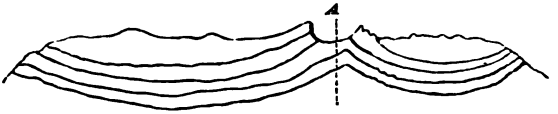


representing the old red sandstone formations of the Mendip Hills and Wick Rocks, the strong black lines the coal measures, and the others the rock with which they alternate—the lowest consisting of mountain limestone; the next, millstone grit; the dotted portion is Pennant grit rock, through which runs the river Avon, as indicated by the indentation at *C*. Above the higher beds of coal, the first horizontal stratum *E* consists of new red sandstone, upon which repose beds of lias *F;* the middle portion here, underlying the bifurcate section of Dundry Hill *D*, consisting of oolite: both these last-named are species of limestone, containing vast quantities of marine shells.

The Vale of Clyde, in the county of Lanark, the most valuable Scotch coal-field, is a vast basin, or trough, the strata composing which crop out at the surface, at variable distances, on both sides of the river. The South Welsh coal-field, comprising an area of upwards of 900 miles, was supposed at one time to form a perfect basin, in the shape of a long-necked flask; but it has since been shown to be rather what is termed an inverted basin, the section, Fig. 2, presenting a rising of the measures on each side of the anticlinal axis *A*.

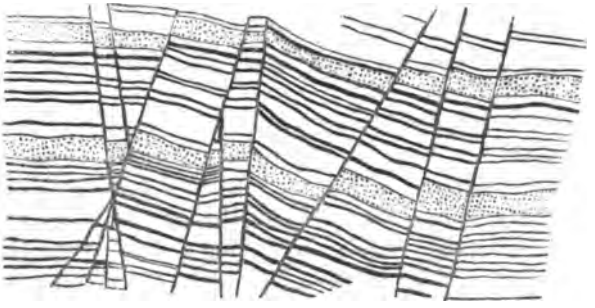
The basin-shape appears to have been the original in all the coal-fields; but, in many instances, this has been subsequently modified by powerful subterranean disturbances, producing slips, dykes and dislocations. These faults, as they are sometimes called, consist of fissures, varying from a fraction of an inch to several yards in width, extending often for several miles, and to an undefined depth; on either side of them the strata have

FIG. 2.



altered their relative position, the rock having not only been rent asunder, but raised on the one side of the fissure, and depressed on the other, although it is impossible to ascertain on which side the elevation, depression, or rather the absolute motion, has occurred. The subjoined section, Fig. 3, illustrates the manner

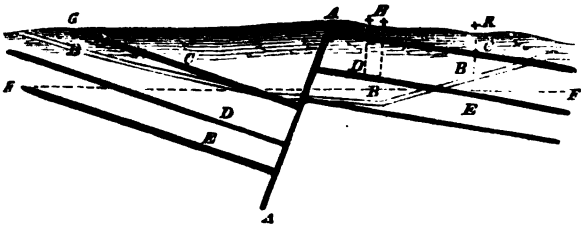
FIG. 3.



in which the strata of the coal measures are dislocated, by faults in the neighbourhood of Jarrow, near Newcastle. Thus the same strata are found at different levels on opposite sides of these faults; the difference of level varying from a few inches to 500, and in some instances to even 1200 feet; whence the violence of the convulsion capable of producing motion in such vast masses may be inferred. The fissures are usually filled with clay, containing fragments of the contiguous strata. Sometimes, however, basalt and other volcanic rocks, appear to have entered them in a melted state from below, changing the nature of all the strata on which they impinge, and, of course, converting the coal, more or less, into coke.

The diagram, Fig. 4, exhibits a section of the great slip of the Northumberland and Durham coal-field, known as the great, or ninety-fathom dyke (*A A*), in consequence of the beds on the northern side being ninety fathoms lower than those on the southern side of it. The section is from a portion of a coal-field near Newcastle. This dyke is in some places 22 yards wide, and is filled with hard and soft sandstone. It is intersected by several other dykes, one of which is 70 yards wide, and by the whin

FIG. 4.



dyke *B B B*, the central portion of which consists of basalt, 16 feet in thickness, and which extends in an undulating course, underground, to a distance of about 11 miles. *C C* shows the high main coal; *D D*, the low main coal; *E E*, the Beaumont seam; *F F F*, level of the river Tyne; *H*, Benwell colliery; *K*, Newcastle town Moor.

A coal-basin always comprises a series of deposits of coal varying from two to sixty in number, and from a fraction of an inch to several feet in thickness, which are separated from each other by numerous strata, consisting chiefly of different varieties of sandstone, clay and shale. Thus, in sinking a shaft at the Gosforth Colliery, about two miles north of Newcastle, the number of strata sunk through reached one hundred and forty-two, the total depth being upwards of one hundred and eighty-eight fathoms. Forty-three seams of coal were pierced; many of them, however, were very thin, and incapable of being worked. Much coal is worked about Newcastle at a depth of 400 feet, and it is generally observed that the thickness of the seam increases with the depth from the surface. The coal in the above locality is covered by so massive a rock of sandstone, that in some cases all wooden supports are unnecessary in the workings. In the South Staffordshire coal-field, the main coal is about 60½ fathoms below the surface in the neighbourhood of Dudley, and is 10 yards in thickness; below it is another bed, 5 yards thick. At Gittersee, in the Valley of Plauen, near Dresden, there are seven beds, between which six thin layers of soft clay intervene.

Although it does not come within the province of this work to enter into details concerning the distribution or statistics of coal, yet the following general summary, taken from Mr. R. C. Taylor's "Statistics of Coal," may not be found uninteresting. The geographical distribution of coal in Europe and America is very unequal in the different countries. The following table shows the relative magnitude of the principal coal-producing countries, and

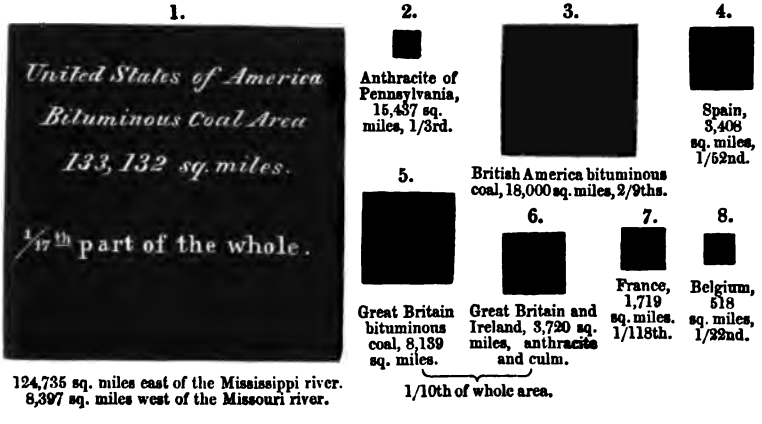
their respective areas of coal land, together with the proportions which they severally bear to each other. Those of France and Spain are considerably less than the actual amount; and Prussia, which is not included in the table, produces nearly as much coal as France.

Countries.	Entire area of each country.	Area of coal land.	Proportion of coal land to the whole area.	Relative amounts of coal area per 1000.
	Square miles, English.	Square miles.		
Great Britain and Ireland . . .	120,290	11,859	1—10	64
Spain (Asturias region)	177,781	3,408	1—52	18
France (area of fixed concessions) in 1845 .	203,736	1,719	1—118	9
Belgium, conceded lands	11,372	518	1—22	3
Pennsylvania, United States	43,960	15,437	1—3	84
British Provinces: New Brunswick, Nova Scotia, Cape Breton and Newfoundland .	81,113	18,000	1—4½	98
United States of America . . .	2,280,000	. . .	1—17	. . .
The twelve principal coal-producing States	565,283	133,132	1—4	724
		184,073		1000

Great Britain and Ireland, therefore, abound most in coal amongst European countries, whilst Belgium, as regards territorial proportion, comes second, although in relative coal area she is the least of the four. Pennsylvania possesses more coal land in proportion to its extent than any other country, although it is exceeded in actual quantity by the British provinces of North America. The area of coal in the United States is nearly three-fourths of the whole amount in the table.

The following diagram, perhaps, conveys at once a more accurate

DIAGRAM OF THE SUPERFICIAL COAL AREAS OF VARIOUS COUNTRIES.


1.
United States of America
Bituminous Coal Area
133,132 sq. miles.
1/17th part of the whole.
124,735 sq. miles east of the Mississippi river.
8,397 sq. miles west of the Missouri river.
2.
Anthracite of Pennsylvania, 15,437 sq. miles, 1/3rd.
3.
British America bituminous coal, 18,000 sq. miles, 2/9ths.
4.
Spain, 3,408 sq. miles, 1/52nd.
5.
Great Britain bituminous coal, 8,139 sq. miles.
6.
Great Britain and Ireland, 3,720 sq. miles, anthracite and culm.
7.
France, 1,719 sq. miles. 1/118th.
8.
Belgium, 518 sq. miles, 1/22nd.
1/10th of whole area.

impression of the relative coal areas of the principal coal-producing countries, than the foregoing table: it is also borrowed from Mr. Taylor's work. These tables, showing the relative areas of coal district in different countries, cannot be taken exactly as an index to the quantities of coal capable of being raised on the respective localities; as the number of seams of coal, their thickness, the ease with which they can be worked, their proximity to economical means of transport, and numerous other circumstances, must all influence, more or less, the productiveness of the mines, and the relative values of the produce. The following table and diagram exhibit the relative annual production, value of the coal, anthracite and lignite, in the six great coal-producing countries of the globe, in the year 1845, from which time up to the present a regular increase has been simultaneously going on in all, and apparently in about a corresponding ratio.

Countries.	Square miles of coal formation.	Tons of fuel raised in 1845.	Relative parts of 1000.	Official estimated value at the places of production.
Great Britain . . .	11,859	31,500,000	642	9,450,000
Belgium	518	4,960,077	101	1,660,000
United States . . .	133,132	4,400,000	89	1,373,963
France	1,719	4,141,617	84	1,603,106
Prussian States . .	Not defined.	3,500,000	70	856,370
Austrian States . .	ditto.	659,340	14	165,290
Total	. . . .	49,161,034	1000	15,108,729

The diagram below exhibits these relations at a single glance.

In nearly all the countries above-named, there is reason to believe that in the ten years preceding 1845 the quantity produced was double what it had been in the previous ten, and in the districts where much iron is smelted the quantity of coal consumed has increased within the last twenty-five years in a vastly more accelerated ratio.

The great number of varieties of mineral coal has given rise to distinctions which are based partly upon age, partly upon appearance, and partly upon quality. In all kinds of coal, without exception, the structure of the wood from which they have been formed is entirely obliterated; partial impressions of single parts of the plants alone indicate their origin. They form a compact deep brown, or perfectly black mass, sometimes dull, but generally possessing a fatty or vitreous lustre, and often exhibiting a play of colours; they present a finely granular fracture, not at all fibrous, and are much heavier than wood, bulk for bulk; they

DIAGRAM OF THE RELATIVE AMOUNTS OF PRODUCTION OF MINERAL COMBUSTIBLES IN THE SIX PRINCIPAL COAL-PRODUCING COUNTRIES OF THE WORLD, IN THE YEAR 1845.

occur more or less stratified, and nearly always are fissured at right angles to the plane of stratification, in a manner similar to that which is observed when a doughy mass becomes dry. These fissures are often narrow, and first appear distinctly when the coals are broken up; but not unfrequently they are found

open or filled with mineral substances, as iron pyrites, calcareous spar, galena, dolomite, heavy spar, gypsum, clay, the soda-salts, and by a double carbonate of lime and iron. Independent of the want of connexion in the coal mass, the causes of which have been referred to, the hardness and solidity of the coal is not very great. The fracture of the shining kinds of coal is conchoidal, of the other kinds it is even or hackly. Common coal, particularly that from more recent formations, is frequently accompanied by a small quantity of a kind of coal which can at once be distinguished from the great bulk by its colour and structure, and still more perceptibly by the difficulty with which it burns; it often appears in thin layers parallel with the plane of stratification, or is disseminated throughout the whole mass of the vein. This variety is often called *fibrous* or *fibre-coal*, it is richer in carbon, and consists of coal somewhat more advanced in the process of mouldering than the other and greater portion, affording a striking exemplification of the process that is going on in all coal. The entire substance of coal, particularly that of the younger deposits, is observed to be made up of portions rich in carbon, with such as are comparatively poor; a mixture, therefore, of coal in two stages of decomposition, of which the one is black, of a pitchy lustre and conchoidal fracture, the other dull, brown, and even. Perhaps an unequal facility of decomposition in the different parts of the plants may be the cause of this; although such a supposition is discountenanced by both stages occurring stratified, and in all manner of relations towards each other, from thin veins frequently alternating, to veins of several inches in thickness, and fragments of these appearing to be homogeneous.

The varieties of pit coal, excluding the anthracites, are so very numerous, and pass so imperceptibly the one into the other, that many specimens can with difficulty be classified under any general denomination, or sub-species. The most marked physical varieties are those generally known in this country as *caking coal; splint* or *hard coal; cherry* or *soft coal;* and *cannel,* or *parrot coal.*

Caking coal is velvet-, or greyish-black, of a shining, resinous lustre, and a small-grained or uneven fracture; when heated it fuses together into a pasty-cake, from which the bubbles of volatile matter escape as from a dough, leaving a coke of a totally different shape to the original coal. It soils the fingers, and breaks up

into more or less cubical fragments; when ignited it burns with a lively yellow flame, but requires frequent stirring, in consequence of its caking property. It is inapplicable in many furnace operations in consequence of this peculiarity, and requires, when used for such purposes, to be previously converted into coke. Its composition will be seen from the tables in the following pages. The principal beds in the Newcastle coal-field are composed of this variety, as is also the sixth bed—reckoning from the surface —in the Glasgow coal-field, and it is also abundant in other localities.

Splint, or *Hard Coal*, is black, with a shade of brown; it possesses a glistening resinous lustre, inferior to that of the cherry coal; the principal fracture is imperfect, curve slaty; the cross fracture is fine-grained, uneven and splintery; it is not easily broken, hence one of its denominations. It is more difficultly kindled than either caking or cherry coal; but affords a lasting and clear fire, giving out much heat. This coal is very abundant amongst the Glasgow beds, and is the most highly prized.

Cherry, or *Soft Coal.*—This most abundant and beautiful variety is velvet-black in colour, with a slight intermixture of grey; it has a splendent, or shining resinous lustre, whence it has derived its name of cherry from the miners. It does not cake when heated. The principal fracture is straight, slaty; different slates varying much in lustre. It is very easily frangible, and there is consequently much waste in mining it. It readily catches fire, but burns away much faster than other varieties. The greater part of the uppermost bed of the Glasgow coal-field and the Staffordshire coal belong to this species.

Cannel, or *Parrot Coal.*—Called *cannel* from its property of burning with a clear flame, like a candle, and *parrot* (in Scotland) from its property of flying off with a loud crackling sound when flat fragments are placed upon the surface of a fire. This coal has a dark greyish-black or brownish colour, the lustre is glistening resinous, it takes a good polish, and can be made into inkstands, snuff-boxes, beads and other ornaments; the fracture is flat conchoidal, frequently slaty. It does not soil the fingers, and is rather difficultly frangible. It abounds at Lesmahago near Glasgow, Wigan in Lancashire, and near Coventry in this country. Jet is only a variety of cannel coal.

In the trade a great variety of appellations for coal are current,

derived chiefly from the names of the pits where they are mined. These may afford some clue to the values of the coals amongst dealers and persons conversant with the trade, but are of no service to purchasers without some previous knowledge of the characters as deduced from experiment. As many as seventy denominations of coal are said to be imported into London, of which between forty and fifty are sent from Newcastle alone.

Compact masses of common coal, possessing a pitchy lustre, are called by some mineralogists *pitch coal;* more distinctly stratified kinds, splitting in a horizontal direction, *slate coal;* such as falls into very thin layers, *leaf coal;* and that which is dull and more massive, *coarse coal,* &c. The classification of coal according to the properties it exhibits when submitted to dry distillation will be noticed in describing the process of coking.

The specific gravity of bituminous coal varies from 1.2 to 1.5. Coal fresh from the pit, when exposed to the air, loses a portion of moisture without parting with the whole, retaining, according to its nature, from 1 to 12 per cent; artificially dried coal reabsorbs hygroscopic moisture from the atmosphere. Coal leaves, on an average, less ash than brown coal or turf, but, in consequence of the substances contained in its fissures, more than wood. Upon this point and the specific gravity of coal, the necessary information is contained in the following table:

Description and locality of Coal.			Specific Gravity.	Ash in 100 Parts.	Observers.
Splint	Wylam Banks, Newcastle		1.302	13.912	Richardson.
	Glasgow Coalfield		1.307	1.128	
Cannel	Wigan, in Lancashire		1.319	2.545	
	Parrot coal, Edinburgh		1.318	14.566	
Cherry	Jarrow, Newcastle		1.266	1.676	
	Chief mass of coal from Glasgow		1.286	1.421	
Caking	Garesfield, Newcastle		1.280	1.393	
	South Hetton, Durham		1.274	1.519	
Coal measures.	Alais, Rochebelle	fat and hard coal.	1.322	1.41	Regnault.
	Rive de Gier (P. Henry)		1.315	2.96	
	Flenû from Mons	fat coal, producing a long flame.	1.276	2.10	
	,, ,,		1.292	3.68	
	Cimetière, Rive de Gier		1.288	3.57	
	,, ,,		1.294	2.99	
	Couzon ,,		1.298	2.72	
	,, ,,		1.311	5.32	
	Lavaysse		1.284	5.13	
	Epinac		1.353	2.53	
	Commentry		1.319	0.24	
	Blanzy (dry coal, long flame)		1.362	2 28	
	Rive de Gier, Grand Croix	fat and hard.	1.298	1.78	
	,, ,,		1.302	1.44	

	Description and locality of Coal.	Specific Gravity.	Ash in 100 Parts.	Observers.
Secondary Formation.	Anthracite, Lamure, Dep. de l'Isère	1.362	4.57	Regnault.
	" Macot	1.919	26.47	
	Common coal, Obernkirchen, Lippe-Sch.	1.279	1.0	
	Céral, Dep. Aveyron	1.294	11.86	
	Noroy, Vogesen	1.410	19.20	
	St. Girons	1.316	4.08	
	Belestet	1.305	0.89	
	Czernitz, Upper Silesia	1.362	5.80	Karsten.
	Gnade Gottes, Lower Silesia	1.285	4.65	
	Glück hülf " "	1.276	0.8	
	Sulzbach, Duttweiler, Saarbrücken	1.258	0.15	
	Wettin, Saalkreis	1.466	24.4	
	Sälzer and Neuack, Westphalia	1.288	0.7	
	Pottschappel, Saxony	1.454	27.7	
	Königin Louise, Upper Silesia	1.280	1.2	
	Königsgrube, " "	1.285	0.6	
	Merchweiler, Saarbrücken	1.282	0.9	
	Frischauf, Lower Silesia	1.518	23.4	
	Hundsnaker, Westphalia	1.338	0.6	
	Beata, Upper Silesia.	1.383	11.9	
	Brazils	1.483	28.4	
	Coarse coal, mixed with Pitch coal	1.48	20.9	Lampadius.
	Slate coal, " "	1.24	22.7	
	" with Fibre coal	1.20	26.3	
	Anthracite	1.37	22.5	
	Slate coal, with a little Fibre coal	1.25	20.2	
	Hard Slate coal, with layers of Pitch coal	1.42	24.0	
	Slate coal, with predominating layers of Anthracite and Fibre coal	1.35	23.4	

The mean specific gravity therefore of a coal with 8.73 per cent of ash would appear to be = 1.33. If, however, those varieties containing an excessive amount between 19.20 and 28.4 per cent of ash are not included in the calculation, a mean specific gravity of 1.30 will be obtained for coal containing on an average 5 per cent of ash.

From the foregoing table no direct connection between the specific gravity and the amount of ash contained in any specimen of coal can be deduced, although Professor Johnson believes such to be the case with coal from the same field, and considers the specific gravity as an index of the purity of coal. In analysing anthracites from Beaver Creek, Luzerne County, he found in four varieties the following relative quantities of ash:

	Sp. gr.	Ashes per cent.
1.	1.560	1.28
2.	1.594	4.00
3.	1.613	5.01
4.	1.630	5.063

In the coal from the basin of Maryland bordering on Pennsylvania a similar result was observed:

Mean specific gravity of two specimens.	Mean percentage of earthy matters in the two specimens.
1.32	7.52
1.35	9.58
1.365	10.35
1.385	11.75
1.485	14.41

From these results it appears that the specific gravity does increase in some cases with the amount of ash; but, as will be seen by the tables in subsequent pages, it is by no means a general fact.

The quantity of ash afforded by coal in a laboratory experiment frequently varies very considerably from that obtained from furnaces in actual work. Thus, it was found by the experiments undertaken for the Admiralty Coal Investigation,* that the average amount of ash yielded in the laboratory from thirty specimens was 5.76 per cent, while the average afforded from the residues of the furnace was only . . . . . 4.62 „ „ leaving a difference, therefore, of . . . . . 1.14, or a less quantity by $\frac{1}{5}$ than by the laboratory operations. In a few instances in this series of experiments the reverse was observed to be the case; and in a large series of experiments undertaken by Johnson upon American coal the reverse was also observed. Here the average amount of ash obtained by laboratory manipulation was 7.76 that obtained from the residues of the furnace . 9.10, showing a difference of . . . . . 1.34 in excess, or 17·27 per cent more ash in the furnace than in the laboratory.

The greater proportion of ash contained in the American coal as compared with the British is probably due, in a great measure, to the care which was taken to select the latter free from slaty matters, it having been generally mined expressly for the investigation; and these substances will find their way into commercial coals, when special care is not taken to prevent it. The amount of ash in several varieties of British coal will be found in the following tables showing the composition of coal.

* Vide Tables at pages 51, 52, 53, 54.

The physical character of the ash of coal generally resembles that of brown coal; but its chemical composition depends much upon local circumstances. In many varieties of coal-ash, silica and alumina predominate; in others, gypsum and iron pyrites, which latter is a highly injurious ingredient for most applications of the coal; besides these, the ashes contain oxide of iron, oxide of manganese, lime and magnesia in combination with carbonic acid, sometimes traces of lead and copper, phosphoric and sulphuric acids, with small quantities of chlorine and iodine, although, rather strange to say, no alkali.

The ashes of seven varieties of bituminous coal have been analysed by Mr. J. A. Phillips, for the Admiralty Coal Investigation, with the following results:

	Name of Coal.	Silica.	Alumina and oxide of iron.	Lime.	Magnesia.	Sulphuric acid.	Phosphoric acid.	Total per-centage.	Percentage of ash in Coal.	Percentage of Coke in Coal.
Welsh.	Pontypool.	40.00	44.78	12.00	trace	2.22	0.75	99.75	5.52	64.8
	Bedwas .	26.87	56.95	5.10	1.19	7.23	0.74	98.08	6.94	71.7
	Porthmawr	34.21	52.00	6 199	0.659	4.12	6.633	97.821	2.91	63.1
	Ebbw Vale	53.00	35.01	3.94	2.20	4.89	0.88	99.92	14.72	77.5
	Coleshill .	59.27	29.09	6.02	1.35	3.84	0.40	99.97	10.70	—
Scotch.	Fordell									
	Splint . .	37.60	52.00	3.73	1.10	4.14	0.88	99.45	1.50	52.03
	Wallsend									
	Elgin . .	61.66	24.43	2.62	1.73	8.38	1.18	99.99	4.0	58.45

The following partial analyses of the ash of some coals and anthracites have lately been published.

Name of Coal.	Matter soluble in water.	Matters insoluble in water, soluble in hydrochloric acid.	Matter insoluble in acid and water.	Total amount of ash in coal per cent.	Experimenters.
Newcastle	7.0	36.5	56.5	2.04	Vaux.
Wigan Cannel*	3.0	31.25	63.75	2.673	
St. Helen's	11.0	25.0	64.0	5.00	
Stafford	14.0	41.0	45.0	0.912 I. 2.76 II.	
Oregon	2.0	10.5	87.5	33.5	
Anthracite	5.7	25.7	68.6	1.583	
Mean of 5 specimens from Clay Cross, Staffordshire	12.462	49.946	37.592	2.807	Ronalds.

A mechanical admixture of iron pyrites is remarkable in all kinds of coal, and is exceedingly objectionable for many of its applications. In some kinds it may be seen in distinct crystals, in others it is so finely disseminated as only to be detected by chemical reagents.

The volatile or organic portion of coal is composed of the same elements as wood, peat and brown coal; their relative proportions, however, are different. A small proportion of nitrogen has been found

* It was in the ash of these coals and those below that Mr. Vaux discovered traces of lead and copper.

in coal, as was the case in brown coal, which under certain circumstances is evolved as ammonia, and is of importance as a source of that alkali. The following tables, showing the elementary composition of bituminous coal and some anthracites are compiled from the results of recent experiments, the names of the observers being added in the first, while the others are derived from the Admiralty Coal Investigation.*

	Description and locality of Coal.	Carbon.	Hydrogen.	Oxygen. Nitrogen.	Observers.
Splint coal.	Wylam Banks, Newcastle	74.823	6.180	5.085	Richardson.
	Glasgow Coal-field	82.924	6.491	10.457	
Cannel coal.	Wigan, Lancashire	83.753	5.660	8.039	
	Parrot coal, Edinburgh	67.597	5.405	12.432	
Cherry coal.	Jarrow, Newcastle	84.846	5.048	8.430	
	Chief coal from Glasgow	81.208	5.452	11.923	
Caking coal.	Garesfield, Newcastle, Deep Bank	87.952	5.239	5.416	
	South Hetton, Durham	83.274	5.171	3.036	
Transition Formation.	Alais, Rochebelle	88.05	4.85	5.69	Regnault.
	Corbeyre, Rive de Gier	86.65	4.99	5.49	
	Rive de Gier, Grand croix, maréchal	86.25	5.14	6.83	
	„ „ „ raffaud	86.59	4.86	7.11	
	Flenû from Mons 1	83.51	5.29	9.10	
	„ „ „ 2	82.72	5.42	8.18	
	Rive de Gier, Cimetière, bourrue	80.92	5.27	10.24	
	„ „ batarde	83.67	5.61	7.73	
	„ Couzon, „	81.45	5.59	10.24	
	„ „ gr. masse	80.59	4.99	9.10	
	Decazeville, Dep. Aveyron, Lavayasse	81.00	5.27	8.60	
	Épinac	80.01	5.10	12.36	
	Commentry, Dep. l'Allier	81.59	5.29	12.88	
	Blanzy	75.43	5.23	17.06	
Secondary Formation.	Anthracite, Lamure, Dep. de l'Isère	88.54	1.67	5.22	
	Anthracite, from Macot	70.50	0.92	2.10	
	Obernkirchen, Lippe-Schaumburg	88.27	4.83	5.90	
	Céral, Dep. Aveyron	74.35	4.74	10.05	
	Noroy	62.41	4.35	14.04	
	Saint-Girons jet	71.94	5.45	18.53	
	Belestat jet	74.38	5.79	18.94	
	Leopoldinengrube, Upper Silesia	73.88	2.765	2.475	Karsten.
	Königsgrube, from „ „	78.39	3.21	17.77	
	Wellesweiler, Saarbrücken	81.32	3.21	14.47	
	Sälzer and Neuak, Westphalia	88.68	3.21	8.11	
	Eschweiler	89.18	0.44	2.94	
	Hundsnak, Westphalia	96.02	3.207	6.45	

* With reference to the specimens for examination, Richardson classified his according to the plan adopted in England (Thomson) into Splint, Cannel, Cherry and Caking coal; Regnault arranged his according to their geological age; and Karsten followed an arrangement of which we shall again speak presently. The transverse lines in the columns of numbers, correspond with the respective divisions in a like order.

MEAN COMPOSITION OF AVERAGE SAMPLES OF WELSH COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Aberaman Merthyr	1.305	90.94	4.28	1.21	1.18	0.94	1.45	85.0
Ebbw Vale	1.275	89.78	5.15	2.16	1.02	0.39	1.50	77.5
Thomas's Merthyr	1.30	90.12	4.33	1.00	0.85	2.02	1.68	86.53
Duffryn	1.326	88.26	4.66	1.45	1.77	0.60	3.26	84.3
Nixon's Merthyr	1.31	90.27	4.12	0.63	1.20	2.53	1.25	79.11
Binea	1.304	88.66	4.63	1.43	0.33	1.03	3.96	88.10
Bedwas	1.32	80.61	6.01	1.44	3.50	1.50	6.94	71.7
Hill's Plymouth Work	1.35	88.49	4.00	0.46	0.84	3.82	2.39	82.25
Aberdare Co.'s Merthyr	1.31	88.28	4.24	1.66	0.91	1.65	3.26	85.83
Gadly Nine-feet Seam	1.33	86.18	4.31	1.09	0.87	2.21	5.34	86.54
Resolven	1.32	79.33	4.75	1.38	5.07	included in ash.	9.41	83.9
Mynydd Newydd	1.31	84.71	5.76	1.56	1.21	3.52	3.24	74.8
Abercarn	1.334	81.26	6.31	.77	1.86	9.76	2.04	68.4
Anthracite, Jones and Co.	1.375	91.44	3.46	0.21	0.79	2.58	1.52	92.9
Ward's Fiery Vein	1.344	87.87	3.93	2.02	0.83	included in ash	7.04	—
Neath Abbey	1.31	89.04	5.05	1.07	1.60	—	3.55	61.42
Graigola	1.30	84.87	3.84	0.41	0.45	7.19	3.24	85.5
Gadly Four-feet Seam	1.32	88.56	4.79	0.88	1.21	—	4.88	88.23
Machen Rock Vein	1.297	71.08	4.88	.95	1.37	17.87	3.85	65.2
Birch Grove, Graigola	1.360	84.25	4.15	.73	.86	5.58	4.43	85.1
Llynvi	1.28	87.18	5.06	0.86	1.33	2.53	3.04	72.94
Cadoxton	1.378	87.71	4.34	1.05	1.75	1.58	3.57	82.0
Oldcastle Fiery Vein	1.289	87.68	4.89	1.31	0.09	3.39	2.64	79.8
Vivian and Sons' Merthyr	1.299	82.75	5.31	1.04	.95	4.64	5.31	67.1
Llangennech	1.312	85.46	4.20	1.07	0.29	2.44	6.54	83.69
Three-quarter Rock Vein	1.34	75.15	4.93	1.07	2.85	5.04	10.96	62.5
Pentrepoth	1.31	88.72	4.50	0.18	—	3.24	3.36	82.5
Cwm Frood Rock Vein	1.255	82.25	5.84	1.11	1.22	3.58	6.00	68.8
Cwm Nanty Gros	1.28	78.36	5.59	1.86	3.01	5.58	5.60	65.6
Brymbo Main	1.300	77.87	5.09	.57	2.73	9.52	4.22	55.4
Vivian & Sons' Rock Vawr	1.301	79.09	5.20	.66	2.41	8.34	4.30	58 6
Coleshill	1.29	73.84	5.14	1.47	2.34	8.29	8.92	56.0
Brymbo Two-yard	1.283	78.13	5.53	.54	1.88	8.02	5.90	56.2
Rock Vawr	1.29	77.98	4.39	0.57	0.96	8.55	7.55	62·50
Porth-mawr	1.39	74.70	4.79	1.28	0.91	3.60	14.72	63.1
Pontypool	1.32	80.70	5.66	1.35	2.39	4.38	5.52	64.8
Pentrefelin	1.358	85.52	3.72	trace	0.12	4.55	6.09	85.0

MEAN COMPOSITION OF AVERAGE SAMPLES OF NEWCASTLE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Willington	—	86.81	4.96	1.05	0.88	5.22	1.08	72.19
Andrews House, Tanfield	1.26	85.58	5.31	1.26	1.32	4.39	2.14	65.13
Bowden Close	—	84.92	4.53	0.96	0.65	6.66	2.28	69.69
Haswell Wallsend	1.286	83.47	6.68	1.42	.06	8.17	0.20	62.70
Newcastle Hartley	1.29	81.81	5.50	1.28	1.69	2.58	7.14	64.61
Hedley's Hartley	1.31	80.26	5.28	1.16	1.78	2.40	9.12	72.31

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Bates' West Hartley .	1.25	80.61	5.26	1.52	1.85	6.51	4.25	—
West Hartley Main .	1.264	81.85	5.29	1.69	1.13	7.53	2.51	59.20
Buddle's West Hartley .	1.23	80.75	5.04	1.46	1.04	7.86	3.85	—
Hastings' Hartley . .	1.25	82.24	5.42	1.61	1.35	6.44	2.94	35.60
Carr's Hartley . .	1.25	79.83	5.11	1.17	0.82	7.86	5.21	60.63
Davison's West Hartley .	1.25	83.26	5.31	1.72	1.38	2.50	5.84	59.49
North Percy Hartley .	1.25	80.03	5.08	0.98	0.78	9.91	3.22	57.18
Haswell Coal Co.'s Steamboat Wallsend . .	1.27	83.71	5.30	1.06	1.21	2.79	5.93	61.38
Derwentwater Hartley .	1.26	78.01	4.74	1.84	1.37	10.31	3.73	54.83
Broomhill . . .	1.25	81.70	6.17	1.84	2.85	4.37	3.07	59.20
Original Hartley . .	1.25	81.18	5.56	0.72	1.44	8.03	3.07	58.22
Cowpen & Sidney's Hartley	1.26	82.20	5.10	1.69	0.71	7.97	2.33	58.59

MEAN COMPOSITION OF AVERAGE SAMPLES OF DERBYSHIRE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Earl Fitzwilliam's Elsecar.	1.296	81.93	4.85	1.27	.91	8.58	2.46	61.6
Holyland & Co.'s Elsecar.	1.317	80.05	4.93	1.24	1.06	8.99	3.73	62.5
Earl Witzwilliam's Park Gate	1.311	80.07	4.92	2.15	1.11	9.95	1.80	61.7
Butterly Co.'s Portland .	1.301	80.41	4.65	1.59	.86	11.26	1.23	60.9
Butterly Co.'s Langley .	1.264	77.97	5.58	.80	1.14	9.86	4.65	54.9
Stavely	1.27	79.85	4.84	1.23	0.72	10.96	2.40	57.86
Loscoe Soft . . .	1.285	77.49	4.86	1.64	1.30	12.41	2.30	52.8

MEAN COMPOSITION OF AVERAGE SAMPLES OF LANCASHIRE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Ince Hall Co.'s Arley .	1.272	82.61	5.86	1.76	.80	7.44	1.53	64.0
Haydock Little Delf .	1.257	79.71	5.16	.54	.52	10.65	3.42	58.1
Balcarres Arley . .	1.26	83.54	5.24	.98	1.05	5.87	3.32	62.89
Blackley Hurst . .	1.26	82.01	5.55	1.68	1.43	5.28	4.05	57.84
Ince Hall Pemberton Yard	1.348	80.78	6.23	1.30	1.82	7.53	2.34	60.6
Haydock Rushy Park .	1.323	77.65	5.53	.50	1.73	10.91	3.68	59.4
Moss Hall Pemberton Four-feet . . .	1.258	75.53	4.82	2.05	3.04	7.98	6.58	55.7
Haydock Higher Florida .	1.218	77.33	5.56	1.01	1.03	12.02	3.05	51.1
Ince Hall Pemberton Four-feet . . .	1.276	77.01	3.93	1.40	1.05	5.52	1.09	57.1
Blackbrook Little Delf .	1.26	82.70	5.55	1.48	1.07	4.89	4.31	58.48
King	1.300	73.66	5.30	1.68	1.58	9.06	8.72	62.4
Rushy Park Mine . .	1.28	77.76	5.23	1.32	1.01	8.99	5.69	56.66
Blackbrook Rushy Park .	1.27	81.16	5.99	1.35	1.62	7.20	2.68	58.10

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Johnson and Wirthington's Rushy Park	1.28	79.50	5.15	1.21	2.71	9.24	2.19	57.52
Laffak Rushy Park	1.35	80.47	5.72	1.27	1.39	8.33	2.82	56.26
Balcarres Haigh Yard	1.28	82.26	5.47	1.25	1.48	5.64	3.90	66.09
Haydock Florida Main	1.267	77.49	5.50	1.27	.88	12.84	2.02	54.4
Wigan Four-feet	1.209	78.86	5.29	.86	1.19	9.57	4.23	60.0
Ince Hall Pemberton Five-feet	1.269	68.72	4.76	2.20	1.35	18.63	14.34	56.5
Cannel (Wigan)	1.23	79.23	6.08	1.18	1.43	7.24	4.84	60.33
Ince Hall Co.'s Furnace Vein	1.314	74.74	5.71	1.53	.96	13.52	4.04	58.4
Balcarres Lindsay	1.26	83.90	5.66	1.40	1.51	5.53	2.00	57.84
Caldwell and Thompson's Rushy Park	1.271	76.17	5.46	1.09	.91	14.87	1.50	58.7
Balcarres Five-feet	1.26	74.21	5.03	.77	2.09	8.69	9.21	55.90
Moss Hall Pemberton Five-feet	1.283	76.16	5.35	1.29	1.05	10.13	6.02	56.1
Moss Hall Co.'s New Mine	1.278	77.50	5.84	.98	1.36	12.16	3.16	57.7
Caldwell and Thompson's Higher Delf	1.274	75.40	4.83	1.41	2.43	19.98	5.95	54.2
Johnson and Wirthington's Sir John	1.31	72.86	4.98	1.07	1.54	8.15	11.40	56.15

MEAN COMPOSITION OF AVERAGE SAMPLES OF SCOTCH AND VARIOUS OTHER COALS.

	Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
		A.	B.	C.	D.	E.	F.	G.	H.
Scotch Coals.	Wallsend Elgin	1.20	76.09	5.22	1.41	1.53	5.05	10.70	58.45
	Wellewood	1.27	81.36	6.28	1.53	1.57	6.37	2.89	59.15
	Dalkeith Coronation Seam	1.316	76.94	5.20	trace	0.38	14.37	3.10	53.5
	Kilmarnock Skerrington	1.241	79.82	5.82	.94	.86	11.31	1.25	49.3
	Fordel Splint	1.23	79.58	5.50	1.13	1.46	8.33	4.00	52.03
	Grangemouth	1.29	79.85	5.28	1.35	1.42	8.58	3.52	56.6
	Eglinton	1.25	80.08	6.50	1.55	1.38	8.05	2.44	54.94
	Dalkeith Jewel Seam	1.277	74.55	5.14	0.10	0.33	15.51	4.37	49.8
Various.	Coleshill Co.'s Bagilt Main	1.269	88.48	5.62	2.02	1.36	0.86	1.62	55.8
	Ewlowe	1.275	80.97	4.96	1.10	1.40	8.20	3.37	54.5
	Ibstock	1.291	74.97	4.83	.88	1.45	11.88	5.99	50.8

AVERAGE COMPOSITION OF COALS FROM DIFFERENT LOCALITIES.

Locality.	Specific Gravity of Coal.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
Average of:	A.	B.	C.	D.	E.	F.	G.	H.
36 samples from Wales	1.315	83.78	4.79	0.98	1.43	4.15	4.91	72.60
18 „ Newcastle	1.256	82.12	5.31	1.35	1.24	5.69	3.77	60.67
28 „ Lancashire	1.273	77.90	5.32	1.30	1.44	9.53	4.88	60.22
8 „ Scotland	1.259	78.53	5.61	1.00	1.11	9.69	4.03	54.22
7 „ Derbyshire	1.292	79.68	4.94	1.41	1.01	10.28	2.65	59.32

AVERAGE COMPOSITION OF FOREIGN COALS.

Locality.		Specific Gravity of Coal.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.
		A.	B.	C.	D.	E.	F.	G.
Van Dieman's Land Coals.	South Cape	—	63.40	2.89	1.27	0.98	1.01	30.45
	Mount Nicholas Break o'Day	—	57.37	3.91	1.15	0.90	9.10	27.55
	Tingal	—	57.21	3.38	1.20	1.32	7.80	29.09
	Jerusalem	—	68.18	3.99	1.62	1.12	5.89	19.20
	Douglas River, East Coast	—	70.44	4.20	1.11	0.70	9.27	14.38
	Tasman's Peninsula	—	65.54	3.36	1.91	1.03	1.75	26.41
	Schonten Island	—	64.01	3.55	0.94	0.85	3.38	27.17
	Whale's Head, South Cape	—	65.86	3.18	1.12	1.14	7.20	21.50
	Adventure Bay	—	80.22	3.05	1.36	1.90	4.80	8.67
	Sydney, New South Wales	—	82.39	5.32	1.23	0.70	8.32	2.04
	Borneo (Lahman Kind)	1.28	64.52	4.74	0.80	1.45	20.75	7.74
	„ Three-feet Seam	1.37	54.31	5.03	0.98	1.14	24.22	14.32
	„ Eleven-feet Seam	1.21	70.33	5.41	0.67	1.17	19.19	3.23
	Formosa Island	1.24	78.26	5.70	0.64	0.49	10.95	3.96
	Vancouver's	—	66.93	5.32	1.02	2.20	8.70	15.83
	Lignite, Trinidad	—	65.20	4.25	1.33	0.69	21.69	6.84
Chili Coals.	Conception Bay	1.29	70.55	5.76	0.95	1.98	13.24	7.52
	Port Famine	—	64.18	5.33	0.50	1.03	22.75	6.21
	Chirique	—	38.98	4.01	0.58	6.14	13.38	36.91
	Laredo Bay	—	58.67	5.52	0.71	1.14	17.33	16.63
	Talcahnano Bay	—	70.71	6.44	1.08	0.94	13.95	6.92
	Colcurra Bay	—	78.30	5.50	1.09	1.06	8.37	5.68
Patagonia Coals.	Sandy Bay, No. 1	—	62.25	5.05	0.63	1.13	17.54	13.40
	„ „ No. 2	—	59.63	5.68	0.64	0.96	17.45	15.64

Some few elementary analyses of American coals have been furnished by Professor Johnson, which will be found in a table below, in connection with the relative value of fuel.

Although nitrogen is found in all kinds of coal (as shown in the last tables), yet no such intimate relation has been traced between it and the qualities of the coal, as is the case with the three other elementary constituents. The sulphur in coal is derived from pyrites. With the increase of carbon, the colour of the coal becomes of a darker brown until it is quite black, the lustre gradually rises from that of pitch to a vitreous hue. On the contrary, coal is more solid when the amount of carbon is diminished. The hardness appears chiefly to depend upon the relative proportions of hydrogen and oxygen, and is augmented by an increase of the latter.

Anthracite.—The oldest of all kinds of fossil fuel, the anthracite, belonging to the transition formation, must be regarded as the last product of the mouldering process, and notwithstanding its similarity in outward appearance, it distinctly differs, both in composition, and by the manner in which it burns, from the other species of coal. As these are related to brown coal, so

is anthracite to common coal. Certain kinds of coal, as those of Lamure and Macot in the table, are classed with the anthracites, on account of the similarity of their properties; these, however, are not the result of an advanced stage of the process of decay, but of the agency of heat accompanying the later elevations of primary rocks. Anthracite is eminently homogeneous and without impressions of plants; it is black, has a decidedly vitreous lustre, a powerful play of colours and a conchoidal, sharp-edged fracture. Its structure is massive. The amount of ash, composition and specific gravity of those specimens which have been examined, are collected in the following table:

Locality of Anthracite.	Specific gravity.	Carbon.	Hydrogen.	Oxygen. Nitrogen. Sulphur.	Ash.	Name of Observers.
Pennsylvania, America	1.462	89.21	2.43	3.69	4.67	Regnault.
Wales, Swansea	1.348	91.29	2.33	4.80	1.58	Regnault.
Mayenne, town and Dep. Mire Baconnière	1.343	90.20	4.18	3.37	2.25	Regnault.
Rolduc, near Aix-la-Chapelle	1.367	90.72	3.92	4.42	0.94	Regnault.
Swansea	1.270	90.58	3.60	4.10	1.72	Jacquelin.
Sablé, Dep. de la Sarthe	1.750	87.22	2.49	3.39	6.90	Jacquelin.
Vizille, Dep. de l'Isère	1.730	94.09	1.85	2.85	1.90	Jacquelin.
Isère	1.650	94.00	1.49	3.58	4.00	Jacquelin.
Wales, Jones and Co.	1.375	91.44	3.46	3.58	1.52 (Including O.)	Admiralty Coal Investigation.
Slievardagh, Ireland	1.59	80.03	2.30	N. 0.23 | S. 6.79	10.80	Admiralty Coal Investigation.

Regnault found 0.37, Jacquelin 0.58 to 2.85 nitrogen. The ash consists of silica, alumina, oxide of iron, and according to more recent observations, also contains chlorides, which, volatilizing during combustion, damage the metallic portions of the stove or grate.

Professor Johnson gives the following composition for the ash of some American anthracites:

Characters and ingredients of Ashes.	Sugarloaf Company's Anthracite, Hazle Creek. 1st specimen. Sp. gr. 1.591.	Sugarloaf Anthracite. 2nd specimen. Sp. gr. 1.574.	Sugarloaf Anthracite. 3rd specimen. Sp. gr. 1.55.	Buck Mountain Anthracite. Sp. gr. 1.559	Summit Coal Company's Anthracite, head of Beaver Creek. 1st specimen. Sp. gr. 1.613.	Summit Company's Anthracite. 2nd specimen. Sp. gr. 1.594.	Stephenson's Bluff Anthracite, Beaver Creek. Sp. gr. 1.612.	Salem-vein Anthracite, Pottsville. Sp. gr. 1.569.	Quin's Run Bituminous Coal. Sp. gr. 1.372.
Percentage of ashes in the coal	4.83	8.73	2.242	3.079	5.01	4.00	3.71	6.75	6.80
Colour	Light-buff.	Reddish-white.	White.	Reddish-buff.	Fawn.	Reddish-grey.	Fawn.	Brick-red.	Grey.
Silica	53.603	45.105	43.68	45.60	54.50	50.25	50.05	50.00	76.00
Alumina	36.667	37.000	39.34	42.75	34.45	38.90	39.04	38.90	21.00
Peroxide of iron	5.590	13.000	8.22	9.43	7.50	8.75	8.75	8.00	2.60
Lime	2.857	1.380	5.76	1.41	2.25	0.85	1.56	2.10	—
Magnesia	1.076	2.430	3.00	0.33	1.30	1.25	1.30	0.90	—
Oxide of manganese	0.186	—	—	—	—	—	—	—	—
Loss per cent	—	1.085	—	—	—	—	—	—	0.40
Sum	99.999	100.000	100.00	99.52	100.00	100.00	100.70	99.90	100.00

A careful examination of the composition of fossil fuel, as shown in the foregoing tables, clearly exhibit a gradual increase in carbon as compared with woody fibre, until at length the hydrogen and oxygen do not amount to 10 per cent. This circumstance becomes still more obvious, when the amount of ash is deducted, as in the following table:

Description of the Substance.	Carbon.	Hydrogen.	Oxygen.
Woody fibre	52.65	5.25	42.10
Peat from Vulcaire	59.57	5.96	34.47
Lignite from Cologne	66.04	5.27	28.69
Earthy brown coal from Dax	73.18	5.88	21.14
Coal from Belestat, secondary	75.06	5.84	19.10
„ „ Rive de Gier, Corbeyre, coal formation	89.29	5.05	5.66
Anthracite, Mayenne, transition formation .	91.58	3.96	4.46

In fact, all three ingredients have disappeared in certain proportions, whilst the carbon, which is always the preponderating element, is least affected.

EFFECT OF HEAT UPON FUEL.

As combinations of organic origin, the kinds of fuel which have here been described, are not very simple in constitution, and therefore offer but slight resistance to external modifying causes; they are bodies easily decomposed, and like all other chemical combinations can only exist within certain limits of temperature, the limit being greater for simple than for complex bodies. The varieties of fuel are not volatile; the chemical equilibrium amongst their elements is destroyed by an increase of temperature long before volatilization can take place; and the decomposition caused by heat, is simply an overthrow of the existing arrangement of the elements, while an immediate re-arrangement ensues with the formation of new compounds capable of existing at the higher temperature. The nature of the new products is therefore mainly dependant upon the latter, and these must vary in quantity still more than in quality as the temperature of decomposition is raised or depressed; while the admission or exclusion of air (oxygen) during the process will still further modify the result. In the former case, the products are immediately subjected to the energetic chemical action of oxygen, with which their elements are forced to combine, and combustion results as a secondary process. In the latter, where decomposition by heat is effected without access of air, we have what is called the process of dry distillation. The products of this operation can be conveniently collected and studied, and the process demands par-

ticular attention, not only because it obtains in every instance of combustion, but because it is instrumental in producing an important transformation of certain species of fuel. It would, indeed, be a very erroneous idea to suppose that the combustion of wood, coal, or other species of fuel, was simply the result of a direct union of atmospheric oxygen with their elements; on the contrary, the heat produced by the burning of one portion causes the dry distillation of the internal parts nearest to it, before they are bought into contact with the air. When these have at length become exposed, they are then first acted upon by the oxygen. In short, it is not the wood which we see burning when a billet is ignited, but the products of its decomposition by the agency of heat. The main points in this process of decomposition by heat in closed vessels (dry distillation) are the following. From the moment in which the elements are forced by the heat to abandon their former state of equilibrium, three circumstances concur in regulating the formation of the new products. These are: first, the temperature; second, the degree of chemical affinity among the elements, increased by their being in the nascent state; and third, their volatility. Hydrogen and oxygen possess the latter property in an eminent degree, while carbon is not in the least volatile; there is a tendency, therefore, in the former to separate and pass off in the form of gas; but chemical affinity coming into play obliges them to unite, and form new compounds, partly with each other, partly together or separately, with carbon. Among the combinations that are possible, those of course will result in which the elements have the strongest affinity for each other under the circumstances and existing temperature. Hydrogen and oxygen combine in the simplest and most stable manner to form water; the excess of hydrogen which is common to all fuel, takes up as much carbon as the temperature admits of, forming light carburetted hydrogen and olefiant gas, while at the same time the united action of the two other elements upon the carbon, gives rise to a series of ternary compounds. The simultaneous production of all these bodies gifted with powerful chemical affinities at a high temperature, induces fresh activity, and products of a subsequent action are the final result. In short, the nature of the process admits of the production of an almost innumerable series of bodies, as many perhaps as there are mathematical combinations, binary and ternary, for every degree of temperature. Many of these products are formed in

every case of dry distillation, some of which require more particular notice. A liquid is obtained in addition to the gases (*carbonic acid, carbonic oxide, hydrogen* and *light carburetted hydrogen*), the lower stratum of which is an aqueous solution of substances, amongst which *acetic acid* and ammoniacal salts are the most prominent; the upper stratum being a mixture of bodies analogous to the resins and ethereal oils, and very rich in hydrogen, is technically called *tar*. *Pyroxylic* or *wood spirit*, a kind of alcoholic compound, is obtained when wood is the substance charred. The products vary when any of the varieties of coal are submitted to dry distillation, we then obtain from the tar, in addition to the substances discovered by Reichenbach (*paraffin, picamar, kreosot, kapnomor, pitacall,* and *naphthaline*), pyrogeneous resin, and numerous oils and coal-tar-naphtha, a liquid containing various neutral, basic, and acid bodies.

The less oxygen there is in fuel, and the more the hydrogen preponderates, as is the case in coal, the more numerous are the products of decomposition, which this element forms with the carbon. However much the formation of highly carbonaceous products may be facilitated by a suitable temperature, in no case are we able with wood, and still less with turf, brown or common coal, to compel the two other elements to combine with and eliminate the whole of the carbon; a certain portion of fixed carbon is always left, its quantity depending chiefly upon the degree of heat applied. The original form and structure of wood, brown coal and turf are retained by the charcoal left by each, so that year-rings and cells may be distinguished in wood-charcoal, which discover the kind of wood from which it was produced. Coal is affected differently, having a different elementary composition. Some kinds pass during the process of decomposition into a soft state, or kind of fusion, so that the gaseous products of decomposition, are evolved in bubbles, as it were, from a paste. The carbon left by common coal is called *coke;* it is filled with cavities, is more or less dense, and has in general no resemblance whatever to the form of the original coal. The natural moisture, as well as the oxygen present in the fuel, which during combustion produces water with the hydrogen, frequently prevent the attainment of the very high temperatures required in furnaces, locomotive engines, and for other purposes. For this reason, it has been the practice, from a very early period, to make use of dry distillation as a means of removing those constituents

of the fuel which absorb heat, or as a means of concentrating the heating power, and confining it to a smaller space. This is the object of *charring* wood, or of converting it into *charcoal*, which series of operations have since been applied to peat, brown coal, and particularly to coal itself, in which latter case the process is called *coking*. From the series of natural, a series of artificial fuels are thus obtained, the production of which we proceed to describe. The manufacture of charcoal and coke is in itself a distinct operation, not directly connected with those to be mentioned hereafter, in which the dry distillation of certain kinds of fuel is practised for obtaining tar and the gases simultaneously evolved.

WOOD CHARCOAL.

On the production of Charcoal.—On examining minutely the process of combustion, when, for instance, the lower end of a chip of wood is ignited, two well-defined periods will be observed. At first, a bright flame caused by the ignition of the volatile products of decomposition, which grows less intense by degrees, and is at last extinguished when the gases cease to be evolved, and the process closes with the faint glimmering of the remaining charcoal. If the chip is gradually inserted into a narrow closed glass tube as the flame goes out, the charcoal cools without glimmering from want of air. It is even possible completely to char the chip, in the manner mentioned above, when the access of air is prevented from the beginning by heating the wood in a close vessel. The original mode of preparing charcoal on a large scale was conducted upon the former principle, without entirely excluding the latter; but in the more recent methods large close vessels have been resorted to. Whatever plan is adopted, the amount of charcoal is always found to be greatest when time is allowed for the oxygen to combine with the hydrogen of the wood and form water. Experience has in fact proved that the slow process of charring is decidedly preferable; this may be seen from Karsten's experiments, by the side of which we place those of Stolze and Winkler. The following are the quantities obtained from 100 parts of air-dried wood:

Species of Wood employed.	Charcoal.*			
	By a quick process of charring.	By a slow process of charring.		
	Karsten.†		Stolze.†	Winkler.†
Young Oak	16.54	25.60	26.1	22.8
Old „	15.91	25.71		
Young Red Beech	14.87	25.87	24.6	17.8
Old „ „	14.15	26.15		
Young White Beech	13.12	25.22	23.8	
Old „ „	13.65	26.45		
Young Alder	14.45	25.65		
Old „	15.30	25.65		
Young Birch	13.05	25.05	24.4	17.6
Poplar	—	—	23.8	17.7
Old Birch	12.20	24.70	24.4	17.6
100 years old Birch, well preserved	12.15	25.10		
Young Deal (*Pinus picea*, D.)	14.25	25.25	23.4	20.6
Old „	14.05	25.00		
Young Fir (*Pinus abies*, D.)	16.22	27.72	21.5	20.1
Old „	15.35	24.75		
Young Pine (*Pinus sylvestris*)	15.52	26.07	23.7	
Old „	13.75	25.95		
Lime	13.30	24.60	22.8	16.2
Ash	—	—	22.1	19.4
Willow	—	—	22.2	15.0
Rye straw	13.40	24.60		
Fern straw	17.00	27.95		
Cane stems	14.65	26.45		

Winkler enclosed his specimens in crucibles surrounded with saw-dust, and heated them quickly to redness. As a general result the woods gave nearly a like amount of charcoal; and when the process was too rapid, only half the quantity.

The cause of this remarkable difference in the relative quantities of charcoal obtained is explained by the greater portion of the volatile products of decomposition being evolved at a temperature of 150° C. (302° F.), leaving a substance resembling charcoal, which is not altered at that temperature, but which contains a considerable quantity of oxygen and hydrogen. Rumford obtained the following quantities of this substance from 100 parts of the different woods:

Oak	43.00 per cent
Elm	43.27 „ „
Maple	42.23 „ „

* Marc. Bull obtained the same results with air-dried American woods, namely, from 21 to 25 per cent, by igniting angular pieces in crucibles, surrounded with charcoal powder.

† The wood used by Karsten was dried in the air, that by Stolze at 100° C. (212° F.), and that by Winkler in a dry room.

Pine	44.18 per cent
Lime	43.59 „ „
Poplar	43.57 „ „

When this substance, which very much resembles the red charcoal or charbon roux, is heated to a temperature above 150° C. (302° F.), it continues to evolve carbonaceous products of decomposition until the temperature attains a red heat. The greater part of the charring process can therefore be effected at a temperature gradually increasing up to 150° C. (302° F.), but requires a red heat to be complete. As much less carbon is contained in the products which escape below 150° C. (302° F.), the obvious advantage of the slow process is due to that fact.

The modes of charring wood may be classified into *such as require access of air*, and *those in which air is excluded*. To the former belong the meiler and kiln processes, distinguished by the moveable or fixed character of the coverings.

Preparation of Charcoal under a moveable covering. In Meiler, or *mounds*.—The meiler consists of a uniformly arranged stack of wood, partially protected from direct contact with the atmospheric air by a moveable covering, composed of turf sods, earth, sand, or charcoal powder, which from its nature enables the burner to regulate the admission of air in any manner that may be required.

The woods that are usually selected for charring are pine, fir, larch, oak, red beech, white beech, ash, elm, alder and birch; the wood from trees of middle age is preferred, both old and young wood affording a charcoal less dense and hard. The proper age of the different woods will depend upon the rapidity of their growth and general longevity, modified, however, by climate and soil. The following data may be taken as a guide:

	Age of perfect growth.	Age at which it may be felled for charring.
Scotch Fir . .	140 years.	80—100 years.
Spruce Fir . .	150 „	70— 80 „
Silver Fir. . .	80—100 „	60 „
Larch	80— 90 „	50 „
Oak	200—250 „	50— 60 „
Red Beech White Beech	120—140 „	120 „

	Age of perfect growth.	Age at which it may be felled for charring.
Elm	80 years.	20— 30 years.
Alder	— „	18— 20 „
Birch	40 „	20 „

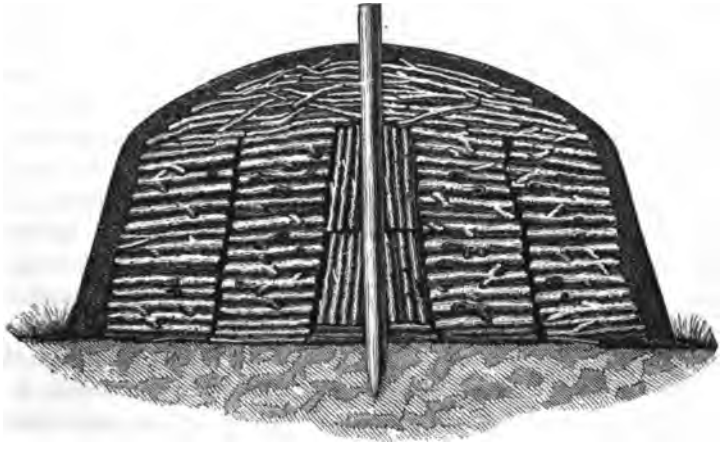
The most appropriate season for felling is the winter, when there is least sap, and when the wood is consequently more quickly dried, and less liable to suffer from dry rot. Half air-dried wood is found to yield the densest charcoal; if the wood is too damp, the heap is kindled with difficulty; if too dry, a waste of charcoal results from its greater combustibility; if the wood has suffered from rot, it affords a less dense charcoal. Wood felled in winter, and properly stacked in an airy situation, will be fit for charring by the end of the ensuing summer. Logs more than 6 inches in diameter must be cleft, and the usual length of the logs is from 3 to 7 feet.

A dry spot is cleared at the proper season of the year, which is during the summer months, sheltered from the wind (by a declivity or a wood); it should be at no great distance from the place where the wood is felled, that the expense of carriage may not be great. The ground must not be damp, or too dry and porous, as in the former case aqueous vapour would rise, and be converted by contact with the red-hot charcoal into carbonic acid and hydrogen; in the latter, currents of air would obtain access to the meiler through the porous soil, and consume a portion of the charcoal. If there is cause to distrust the dryness of the locality, it is well to cover the ground itself, or after having first made a litter of shingles, planks or billets, with a layer of charcoal powder several inches in thickness. The construction of the meiler commences at the centre by erecting the stake or quandel as an axis, from which the meiler is afterwards set on fire. This is either a strong post, around which the logs are arranged concentrically, taking the precaution to leave a free channel at the bottom from the stake to the periphery, that burning coals may be introduced, or three perpendicular logs are connected together with cross-pieces, so as to leave a kind of open chimney. Whichever plan is adopted, the ignition always begins from the foot of the stake.

Easily combustible pieces, such as partially charred wood from a former process, are placed about the stake, and round these the logs, which must be as nearly as possible of the same length, and

so arranged one above the other in the form of a ring as to leave as small a space between them as possible. The hewn logs are arranged with their sharp edges towards the stake, the bark side being outermost, and all spaces occasioned by crooked blocks must be carefully filled up with small wood, &c. The more slanting the logs are placed, the more loosely they will lie together, and vice versâ; on that account the external surface of the mound is made as steep as is consistent with its stability and the attachment of its external covering. It is also quite evident, that many spaces must be left when the logs are laid horizontally and in a radiating manner round the stake in one or more concentric rings, from the great divergence of outer ends of the logs forming the inner rings. A combination of both forms, as shown in Fig. 5, is therefore

FIG. 5.



practically the best, and the meiler is constructed by placing a number of billets in an upright slanting direction round the stake as a nucleus, and ranging the other logs round this in the form of a ring pressing tightly the nucleus, so that its inclination determines the inclination of the whole heap. In consequence of the laws connected with the management of forests in many countries, all the logs must be of the same length, the upper horizontal logs approach consequently nearer to each other, in proportion to the lessening diameter of the nucleus; thus the external surface becomes surrounded with a series of small steps, which serve a very useful purpose in supporting the covering. In all cases the

upper part of the heap is covered with various odd pieces of wood, until it assumes a rounded appearance.

FIG. 6.

Fig. 5 represents what is called a horizontal meiler. Fig. 6 represents a section of an upright or vertical meiler, the names having reference to the manner in which the logs are arranged round the quandel. In Fig. 6 the quandel is composed of three upright stakes placed at about a foot from each other, and prevented from approaching by cross-pieces of wood. The space between these stakes is filled with brushwood, chips, and other easily combustible matters, to facilitate the ignition of the meiler. Round the quandel the logs are placed in an upright position, the outer logs being more inclined than those in the centre, in order that the covering may be supported. The upper part is covered with smaller logs in a horizontal position. The logs must be packed as closely as possible together, in order to avoid too rapid a circulation of the air; and it is sometimes advisable to fill up the interstices with charcoal powder from a former operation. The irregularly formed logs which cannot be cleft, roots, and similar pieces, are always placed in the neighbourhood of the quandel, where they are subjected to the action of the heat for the longest time. When the meiler is constructed, as in Fig. 6, of two series of logs, the one placed upon the other, special care is requisite to avoid too many spaces being left at the points of support; and to obviate this as much as possible, it is usual to turn the thick ends of the lower series up, while those of the lower are placed down. The bark side of the logs is always turned away from the quandel.

The size of the mound depends upon circumstances, but must not exceed such dimensions as will admit of a good regulation of the heat; some are constructed 10 feet in diameter, and even

less, and they may extend to 20, 40, or even 60 feet. It is obvious that the advantage of being less subject to cool is in favour of a large meiler, as its surface is small compared with the space it occupies. The outer surface of a mound 30 feet in diameter, viewed as a hemisphere, will be the $\frac{1}{3}$ of its contents, while that of a mound 60 feet in diameter will only be the $\frac{1}{10}$, so that the surface exposed in the latter will be comparatively only half as great as in the former. The interstices of the meiler having been filled up with small wood, it is next protected from the air, and provided with a *covering*. Moist charcoal powder is best suited for this purpose, as it packs easily and closely together. Sand and earth are not so applicable; any of these matters, however, would fall into the crevices between the logs of wood, if a layer of turf, the earthy side outermost, with leaves, or even in cases of necessity with moss, were not first interposed. This first covering does not extend to the bottom, but is supported at a few inches from the foot by a layer of twigs and brushwood, held by forked uprights in the form of a ring against the heap, which is called its *armour*. This open part at the foot is left for the escape of the aqueous vapour which is evolved in the beginning, and could not be allowed to escape from any aperture in the upper part of the meiler, as too much draught would thereby be caused, with the consequent destruction of much of the wood. The covering, which is from 3 to 5 inches thick at the sides, is made still thicker on the top. When the second covering of charcoal powder or sand has been pressed down, which, however, is sometimes done at a later period, the meiler is then ignited; early in the morning red-hot coals are brought by means of the channel at the foot of the meiler, or, on the other plan, from the top, to the base of the stake, and the half-burnt pieces and chips about it are ignited as quickly as possible. When this is done, and the opening again closed up, the first period begins, namely, that in which moisture is expelled from the wood, and which is called the *sweating*.

Fig. 7 represents a meiler with its complete covering ready for igniting.

a The top of the stake or quandel.

b The mouth of the channel for introducing fire, which is afterwards closed.

c The lower, and *d* the upper armour.

The most careful watching is necessary, at this period of the

process, to prevent the heap being destroyed by explosion and too rapid an evolution of vapour. The duration of the sweating process is easily ascertained by the nature of the smoke, which

FIG. 7.

passes off in the form of a yellowish-grey cloud, while a portion of the vapours condense in the covering, making it quite moist. As soon as the nature of the smoke changes, becoming grey and lighter, the open part below the armour is covered, and the second period of the process, or the *charring*, commences. The state of the meiler now needs repairs of an important kind; the wood of the stake having been gradually consumed, cavities are left which cause a sinking in and falling together, the covering becomes damaged, and apertures are produced through which air would be admitted. By quickly removing the covering, the top or *cap* of the meiler is left bare for a moment, and the wood in the neighbourhood of the stake is broken up, and beaten down with a long pole, the empty space filled up with fresh logs, and the covering immediately replaced and pressed down. The combustion of the smaller portion of the wood now causes the dry distillation of the remainder, and the charring, properly so called, commences. The meiler is now left to itself for several days, care being taken that openings are made at the foot, to allow the vapours of tar to pass out, and to supply the necessary amount of air, which, however, is partly effected by the porosity of the covering. The circumference of the heap now visibly diminishes, and attention must be paid to see whether this diminution is greater in some places than in others, or whether it presents a general uniformity. If the former is the case, a change of direction must be given to the process by increasing the thick-

ness of the covering in those parts, or by making holes exactly opposite to them, which produce a draught in a different direction. The labour of the charcoal burner would now be at an end, if certain parts of the heap did not require additional care. It is impossible to keep up the fire immediately below the covering, the wood in those parts being too much cooled, and the condensed vapours which collect there, impede the progress of the combustion. It therefore becomes necessary before the process is completed (at a time when the wood in the interior is completely charred) to conduct the combustion to the very outside of the heap, by the access of more air.

For this purpose, a second series of holes are quickly made in the upper part of the breast of the meiler, parallel with those in the foot, but at greater distances from each other. It is not necessary to make these holes higher up, as the draught naturally ascends, and produces sufficient heat in the upper parts. After a short time, the thick black smoke which at first escapes from these upper holes assumes the form of a thin blue cloud, the openings are then immediately closed, and fresh ones made about 2 feet lower down, when the same appearances occur a second time. Very large heaps require a third series of holes, close to the foot of the meiler. When fire partially issues forth instead of smoke, simultaneously all round, the process is known to be successful. Wherever flames break out, they are immediately extinguished by moist charcoal powder, and in those places where they do not quickly appear, fresh holes are made to facilitate their production, until at length the whole heap is under cover, and the process complete.

The general appearance of the meiler gives some clue as to the nature of the result; although in every case a great contraction has taken place, with careful management this is exceedingly uniform, while an inclined position, bulging and the like, prove the contrary. The charcoal would be ignited and destroyed by breaking up the whole heap before it had cooled, and to wait until it had completely cooled, would involve a great loss of time; the logs of charcoal are, therefore, drawn out separately. The burner lays bare an aperture of tolerable size at the foot of the mound, draws out by means of a hook as much charcoal as time will permit before the air acts too strongly through the opening, and then immediately closes it again; this is repeated round the entire heap, and the red-hot charcoal which is drawn

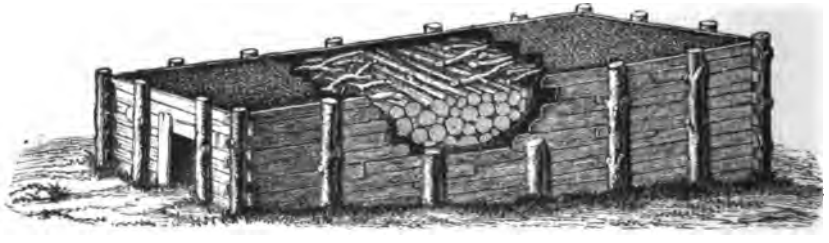
out is extinguished by imbedding it in sand, charcoal powder, or by water; the operation is best performed at night, when the slightest spark is visible. The time required for charring varies with the size of the meiler; small meilers will require from six to fourteen days; but four or five weeks are necessary when the diameter is above 40 feet.

Charring in Heaps.—Another method of burning charcoal, differing from the preceding in the mode of arrangement and management, but not in principle, is practised in some countries, as at Wienerwald; it is called carbonization in heaps or piles (*Haufenverkohlung*). Round, uncleft logs, of very variable diameter, are usually charred in the heaps, the different sizes enabling the workmen to pack them closely together. It is also desirable to remove the bark from the logs, by which means the fire is more uniformly and easily spread through the entire heap. The removal of the bark should take place immediately after the wood is felled, as it then dries in a very much shorter time. It has been observed by Af Uhr, that pine-wood, felled in June, and placed in a shed to dry, lost the following amounts of moisture, according as it was entire or deprived of bark:

	From June to:				
	July.	August.	September.	October.	
Whole logs . . .	0.41	0.84	0.92	0.98	Percentage of original weight.
Logs deprived of bark .	34.53	38.77	39.34	39.62	

The wood deprived of bark was thus fully air-dried in three months, while the whole wood had only lost about 1 per cent of its weight. The wood is arranged in the form of a narrow, long-shaped wedge (Fig. 8), the breadth of which is entirely occupied

FIG. 8.



by the blocks, while the length is generally from 20 to 30 feet. The thick end, which is likewise the last as regards the course of the process, is from 7 to 9 feet in height, the front thin end being only 2 feet above the level of the ground.

Independent of the lesser height of the heap in front, the gentle slope of the selected spot gives it an inclination in that direction, so that there is a gradual rise towards the back. The choice of position and the mode of covering are the same in this as in the meiler process. The erection is commenced by driving posts all round the measured quadrangle, which in breadth and length must exceed that of the future pile; these posts must be higher towards the back, and correspond in every respect with the height of the pile. Having arranged the unhewn logs, 8 feet in length, crossways upon a floor consisting of long poles placed lengthways, and thus formed the pile, a space 6 inches wide is left between the posts and the sides of the logs, for the reception of the covering, which could not otherwise be attached to the perpendicular sides.

Boards, shingles, or other flat pieces of wood, are placed in the inside against the posts, and wet charcoal powder is stamped between them and the logs, until the whole side is covered. The thicker end is often constructed in the form of a flat arch, which sufficiently supports the covering without boards. When all the interstices have been filled up, the roof-shaped surface is supplied with a triple covering of twigs, leaves, and lastly of charcoal powder. On the two long sides a number of holes are previously made in the planks (not in the covering), and a larger one of the same kind in the front for the introduction of small wood for ignition, which is accomplished by thrusting red-hot coals between the poles and the pile. When the fire has kindled, which may be seen by the smoke, the hole is immediately closed; about 15 inches from the ground, other holes, 3 or 4 inches in diameter, are made in the front. The portion of the pile between these now begins to draw, whilst the adjoining higher, thicker part is in the sweating stage. The chief points to be attended to in this process of charring, are the gradual dissemination of the heat and the protection of the charcoal from the access of air. If blue smoke escapes from the openings, the process is known to be drawing to a close, the open spaces are closed and fresh ones made at a greater height from the ground, and so on throughout the whole pile. In order to draw the fire down to the bottom, which is more difficult on account of the cooling and humidity, a few spaces are made immediately above the ground in that part, which is already nearly charred. When the charring process is advanced about

as far forward as the pile is broad, the first portions of charcoal are drawn out. It is sometimes thought preferable to split the logs, and place them longitudinally in a parallel direction with the sides of the pile, by which arrangement the carbonization is more easily diffused, and fewer openings are required. A well-grounded preference is given to charcoal prepared in this manner; the charcoal being removed from the heat as soon as it is properly charred, is generally of a superior quality. When this method is properly carried out, the fire should not progress more than 1½ foot daily, so that a heap of 24 feet in length will require about sixteen days for completion, and a heap of 60 feet in length about six weeks.

General Remarks upon Heaps and Mounds.—The process of charring wood, which has been known for two thousand years,* belongs undoubtedly to that numerous class of inventions, which the correct practical discernment of former times has left little to modern theory to supply beyond the rational explanation. Simple and ingenious as the process is, it has not been modified by any essential improvement. It is impossible to imagine a spot where wood is felled, or to which it is brought by flooding, or by wooden sledges, which does not offer the simple requisites for the erection of a meiler; and this circumstance is of importance, as the cost of carriage upon wood very far exceeds that upon charcoal. It has also already been remarked, that wood diminishes in bulk during charring, as much as from 20 to 25 per cent, so that a heap comprising 3,600 cubic feet, becomes 2,250 cubic feet when charred, leaving an empty space of 750 cubic feet, from which the air must be excluded or it would destroy and waste a portion of the wood. This vacant space is not however produced in the meiler, because the flexible covering, yielding as the wood shrinks, prevents the possibility of such an occurrence. No arrangement could so surely, effectually, and easily regulate the access of air, upon which the main point in the operation depends, as the moveable covering. Each thrust of the pole is like opening a stop-cock, each shovelful of earth like closing another, and lastly, the fire can be brought to act consecutively upon every part of the mass of wood, however extensive it may be. The object of the charcoal burner, is to char by dry distillation the greater portion of the wood at the expense of the smaller, which latter, in being consumed, affords

* It is described by Theophr. Erosius, who lived 300 years A.C., and by Pliny.

the requisite heat. A certain portion of the contents of the heap must be considered as the necessary fuel with which the burner effects his purpose. While the admitted air partially consumes the one log, the adjoining one is exposed to the heat which it evolves, undergoes dry distillation, and is itself afterwards, for a short time, exposed to the action of atmospheric oxygen. The ability of the workman is shown in excluding the air from the wood at the precise moment that the neighbouring parts are undergoing spontaneous decomposition. This part of the operation is very much facilitated by forcing the vapours, contrary to their natural course, to take a downward instead of an upward direction; the process is thus retarded while the workman is enabled clearly to discern what changes are taking place, and at the same time leisure is afforded him for taking the necessary precautions. It may also be remarked, that the fire beginning in the middle of the heap, gradually proceeds to the circumference, and thus the centre of the heap, which is the first to be completely charred, is protected from the destructive influence of oxygen by an enclosure of burning wood impermeable to air.

In every process of charring in which one portion of the substance is charred at the expense of another the current of air by which the combustion is supported must proceed as far as possible from the unburnt portion to that which is undergoing combustion.

If a small piece of wood is ignited, and the burning end held downwards, as is shown in Fig. 9, so that the current of air proceeds from the burning to the unburnt extremity, the wood will be speedily reduced to ashes; if, on the contrary, the ignited end be held uppermost, so that the current of air is established from the unburnt to the burning extremity, the portions already half burnt are surrounded by the products of the combustion of the parts below them, which exclude the free access of air and prevent their reduction to ashes. But when the greatest possible amount of charcoal is desired, although the products of the combustion of the one portion are less prejudicial than atmospheric air as an envelope for the red-hot

FIG. 9.

charcoal, yet even these should be as much as possible excluded from contact with it. The products of the combustion of wood consist chiefly of carbonic acid, carbonic oxide, hydrogen, carburetted hydrogen, aqueous vapour and the vapours which subsequently condense to form tar. If a current of carbonic acid is carried through red-hot charcoal, every equivalent of carbonic acid becomes converted into two equivs. of carbonic oxide by taking up carbon from the charcoal. Carbonic oxide, carburetted hydrogen and hydrogen are not altered by passing through red-hot charcoal, nor do they affect the charcoal; aqueous vapour is however decomposed, producing with carbon, at first carbonic acid, which then becomes carbonic oxide, and hydrogen. These products, therefore, if allowed to pass through the ready formed charcoal must diminish its quantity.

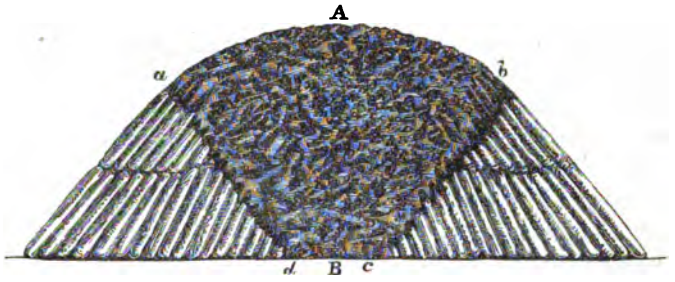
Both in the meiler process and in the heaps at the time of ignition, and for some time after, during the sweating, the direction of the draught is necessarily from the burning towards the unburnt wood; a portion is consequently reduced to ashes, and hence the necessity for refilling the space thus left vacant. During the true charring period very little air has access to the meiler, and the two conditions most essential to a good yield of charcoal are closely observed. The air that finds access is in the direction from the unburnt to the burning portion, and if some holes are made in the upper part of the meiler, the products of combustion escape through these without traversing the red-hot charcoal. The same is the case until the process is completed, and it is only during the first period of the operation that some better arrangement is desirable. This has been partially effected in stationary meilers, upon the plan proposed by Brune.

At the commencement of the true charring process the interior of the meiler presents the appearance indicated in Fig. 10, according to the experiments of Ebelmen.

The charred portions surround the quandel in the form of an inverted truncated cone, *a*, *b*, *c*, *d*. If smoke-holes are made at *a* and *b*, the products of combustion which escape through them, do not pass directly through the red-hot charcoal, while the current of air entering through the covering and at the uncovered foot is in the direction from the unburnt to the burning portions.

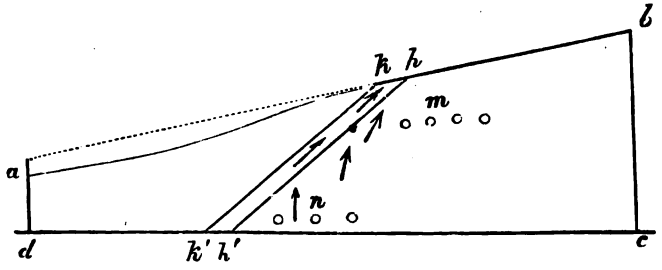
In the heaps, it is always the object of the burner to

FIG. 10.



advance the charring process in the upper part before the lower, so that if *a, b, c, d,* Fig. 11, represent the longitudinal section of

FIG. 11.



a heap some time after ignition, *a k k' d* will represent the charred portion which has somewhat sunk together, *k k' h' h* the zone of wood actually undergoing decomposition, and *h h' c b* the wood which is more or less unchanged. The charred portion is surrounded with the close-fitting covering, the air entering by the holes *n* is drawn towards the inclined zone of decomposing wood, where it supports the combustion, and passes off with the products of decomposition through the loose covering above the zone, and through the draught-holes *m*. The essential conditions, before adverted to, are consequently carefully followed. The air traverses the heap in a direction from the unburnt to the burning portions of the wood, and the volatile products do not pass off through the charred product. No great difference is therefore to be drawn between the theoretical efficiency of the two methods of charring. The heaps, however, offer a comparatively much greater surface for the admission of air through the covering, a disadvantage which is partly compensated by the opportunity they afford of drawing portions of the charcoal before the entire heap

is charred. Although on the whole the meiler may have the advantage of affording a larger percentage of charcoal, the smaller amount of labour required in adapting the logs for the heaps, the greater facility of covering, and the superior qualities of the charcoal, which is both denser and in larger pieces, render the latter process preferable under many circumstances.

Ebelmen has endeavoured to ascertain what portion of the combustible ingredients in the meiler process are consumed in converting the remainder into charcoal. Is the wood charred at the expense of the volatile products of the dry distillation, or at the expense of a portion of the charcoal? The conclusion at which he arrived, from the comparative analysis of the gases from the meiler and gases from a retort in which wood was charred, was in favour of the view that the whole of the heat necessary to char the wood in a meiler was derived from the charcoal; that, in fact, the volatile products of decomposition were primarily the same in both methods of charring, but the gases from the meiler process were mixed with the products arising from the combustion of additional charcoal at the expense of the oxygen of atmospheric air. Scheerer, however, has shown* that it is nearly impossible to estimate accurately the amount of charcoal thus consumed, and that the volatile products of decomposition in the meiler process must be consumed to a considerable extent. He calculates that at least $\frac{1}{4}$ of the tar is burned.

At Hiflau, in Styria, and at Reinhardswalde, the process of charring in meilers has been modified in some respects, with a view to increase the quantity of charcoal. The meiler is erected on a porous foundation constructed of stones and sand, the foot is closed during the first part of the operation, and the ignition is effected at the top instead of the bottom of the stake or quandel, the air being forced by this arrangement to traverse the meiler in a perpendicular downward direction from the top to the bottom of the meiler; the necessary heat is communicated almost entirely by the dry wood, which is filled in at intervals from the top. In these processes less air is admitted to diminish the yield, but the charcoal is more subject to the action of the gases produced during the charring, the effect of which has been described above, and which in some

* Lehrbuch der Metallurgie.

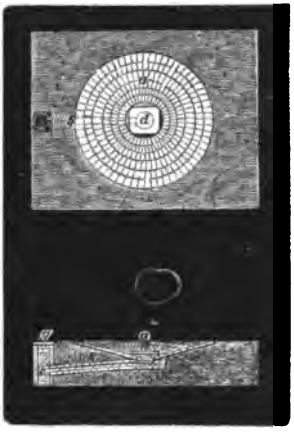
measure counterbalances the advantage derived from the lesser quantity of air.

The great drawback to the meiler process is the total loss of all available secondary products, such as tar and pyroligneous acid; and many improvements upon the process have been proposed with a view to secure these. The advantageous disposal of these products is very much dependant upon the wants of the surrounding district, and is often exceedingly difficult, and yet various methods for collecting them have been tried, though not always with success. The means adopted for collecting the secondary products in the meiler process have generally proved unsatisfactory, in consequence of the inferior quality and lesser quantity of charcoal which have been then obtained. Some have proposed to form the covering of slaked lime, in order at all events to preserve the acetic acid as acetate of lime; others, that it should consist of portable hurdles covered with clay, which being supplied with tubes might carry off the vapours to condensing vessels. This, however, would be robbing the covering of its most useful quality, its flexibility. The long heaps or piles are better suited for condensing arrangements, and the best plan is to place a tube in the covering at the thicker end which shall conduct the vapours to a vessel containing water. When it is not necessary to change the spot chosen for the heap and follow the wandering course of the woodman, where the wood, as in mountainous districts, can always be brought to the same spot by sledges or otherwise, a stationary meiler may be constructed, and the base of the heap may be built in the form of a flat funnel, the middle and lowest part of which, is connected with a channel leading to a pit at the side, in which tar and pyroligneous acid may be collected.

Stationary meilers are sometimes constructed on a nearly horizontal circular bed of brickwork, either inclined from the circumference towards the centre, or from the centre towards the circumference. In the former case, a short perpendicular tubular space is left in the centre, leading to an inclined channel, which ends in a small brick tank or reservoir at the side, in which a portion of the condensable products of combustion collect during the process. The tubular space is loosely covered with a grate or iron plate to prevent the charcoal from falling into it. The reservoirs must be covered during the process, so as to prevent the air from entering through the central aperture, and the products

cannot be removed until the charring is completed. A construction of this kind is shown in Figs. 12 and 13.

FIGS. 12 AND 13.



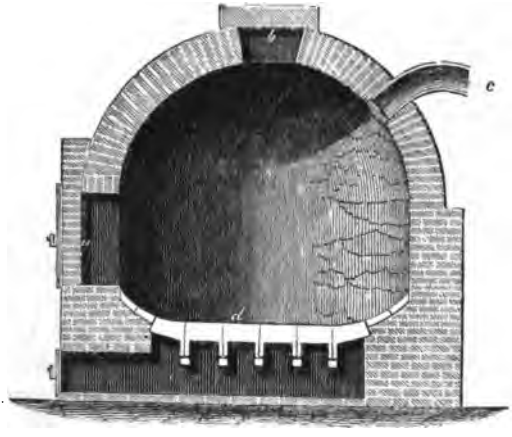
The ignition of the meiler, when stationary, may be advantageously effected by modifying in some measure the construction of the foundation, as proposed by Brune, and alluded to above. Instead of piling the wood upon the brickwork an annular wall of brickwork is erected about 1 foot or 1½ feet from the surface, upon which are placed iron plates supported by cross-bars of iron. Three apertures are left in this wall for the admission of air below it; and into this space brushwood and other combustible matters of little value are placed and ignited, by which means the iron plates become red-hot, and communicate their heat to the wood in the meiler above them. By closing the apertures in the wall the draught can be regulated. It is found unnecessary to heat the entire surface of the iron plates in order to ignite the meiler; a heated surface of 5 feet in diameter, when situated in the centre, being sufficient to ignite a meiler of 30 feet diameter. This method, according to a report by Ebelmen, affords a larger produce of charcoal than when the ignition is effected in the usual manner by a quandel shaft. Although the quantity of air admitted to the meiler during the sweating part of the process is much diminished by this method of ignition, yet a considerable quantity must be admitted to keep up the requisite temperature, and none of the attempts to improve this part of the process have as yet proved satisfactory.

Charring in Kilns.—The attempt to obtain all the products simultaneously, with a greater amount of charcoal, probably first led to the substitution of stationary apparatus, either of brickwork or iron, in place of the covered meilers. Some of these arrangements are calculated, like the heaps, to produce the necessary temperature for charring, by the combustion of a portion of the wood, and the admission of a little air: such as kilns, the sides of which form a fixed covering for the substances to be charred. In others, the portion of the wood destined to produce the heat is

entirely separated from that to be charred, the latter is placed inside, the former outside the kiln. The gases and vapours evolved from wood in the process of charring, in as much as they are the products of dry distillation and unconsumed, being themselves fuel, and being unavoidably lost in the heaps; it becomes an object when these are evolved in large quantity, to bring the operation as quickly as possible to a close, so as to retain the combustible ingredients in the charcoal.

In the kiln represented at Fig. 14, the air has access through the bars of a grate at *d*. The kiln is filled through the aperture *a*, and afterwards from *b* in the roof; the charcoal is only discharged at *a*. All the openings are bricked up during the operation. The draught is regulated by means of a tightly fitting door to the ash-pit. The air is allowed access until the walls of the furnace have attained a heat sufficient to complete the carbonization, the doors are then completely closed, and earth is thrown against them, when the thick smoky vapours of tar make their appearance. The volatile products escape through the pipe *c*, which is connected with a condenser. The process in these kilns is not so easily watched or so much under command as in the meiler, where the moveable covering indicates the progress of the operation. A very long time elapses before the charcoal is sufficiently cool to remove, and the kilns require frequent repairs, which increase the expense of the manufacture. On the other hand, the kilns can be more regularly worked, being independent of the weather.

FIG. 14.



In Russia, Sweden, and according to Kavanko in China, carbonization is usually effected in pits, the sides of which are made to form the kiln. The pit is generally situated on the side of a hill, and in the shape of an inverted cone; at the side is a tar

vessel, which is connected with the sole of the kiln by an inclined tube. The pit having been filled with finely cleft wood, is closed at the top with a covering of earth, through holes by which a draught is produced. The kiln proposed by De la Chabeaussière is a carefully constructed pit, which is worked upon the same principle, and which, like the preceding, is more adapted for the production of tar than of charcoal. The form being the same, a draught is produced from below by means of a number of channels, which pass down the sides of the kiln, opening laterally above the sole. The whole is covered above with an iron hood, in such a manner as to allow the conducting pipe for the tar to enter a few inches below it. In consequence of excessive cooling, a quantity of wood in these kilns remains only half charred.

The kilns, in which carbonization is conducted by means of a series of holes made in the wall, are different from the above. They are made to contain from seven to eight stacks (100 cubic feet each) of wood, are quadrangular that the wood may be more closely packed, and slightly arched at the top. The lowest series of holes is on the same level with the sole, the next 18 inches higher, and the remainder at distances of 3 feet from each other. The wood having been introduced, and packed as closely together as possible, a channel is made above the sole, corresponding with and accessible by the doors, by means of which the whole is ignited. A pipe from the upper part of the furnace carries off the vapours. Distinct apertures are left for charging the furnace, and drawing out the charcoal. When the process has begun in the kiln, and a certain temperature has been attained, the holes are closed, one after the other, with clay plugs as the process progresses, and when it is nearly finished the whole furnace is covered with clay. The charcoal must not be removed until the furnace is completely cold, or the air, on entering would consume a large proportion of the red-hot charcoal. It requires two or three weeks to cool.

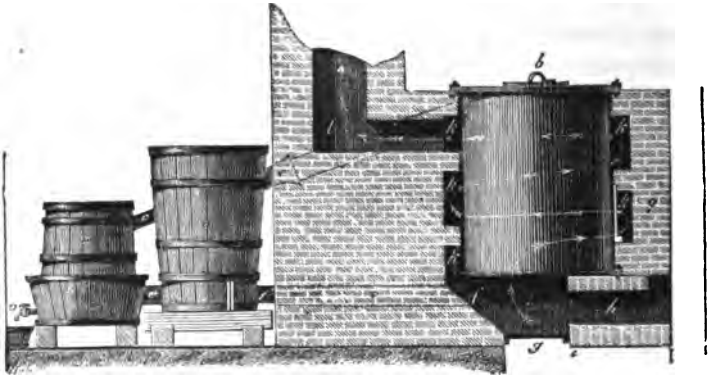
The second kind of kilns, which are heated by fire from without, and which entirely exclude the access of air, admit of all the products being completely collected, an advantage which is counterbalanced by the necessity of employing small vessels and small quantities of wood at a time, that the bad conducting power of wood and charcoal may not offer an insurmountable obstacle to the penetration of the heat to the central portions.

In addition to this, the cost of fuel for effecting the dry distillation becomes a serious obstacle, amounting generally to

20 or 25 per cent of the wood to be charred; and although the gases, after the condensation of the tar, have been economized in some forms of apparatus, and burnt under the retorts as fuel, yet the process has, nevertheless, not proved profitable.

Coniferous woods have been found to produce the largest amount of tar, on account of the highly hydrogenized resins and the turpentine, with which they are impregnated; those parts which contain the most resin are, therefore, chosen. Kilns, or rather retorts of this description, are more applicable to the production of tar, and the volatile products of dry distillation, than of charcoal; they are, indeed, generally called *tar retorts* or *furnaces*, and are often constructed entirely of clay, in the vicinity of the spot where the wood is felled. They consist of two hollow cylinders, one within the other, arched over at the top; the inner one, destined to receive the resinous logs, extends with the aperture in its dome somewhat beyond the outer one, which, leaving an annular space of a few inches, rises close up to the dome. The space between both is appropriated to the fire, a few holes being left in the outer cylinder for the admission of air. The bottom of the inner cylinder is made in the shape of a funnel, terminating in a tube, leading through the intermediate space and the external cylinder to the tar cistern. When the furnace is charged with wood, the aperture is closed, and fire is made in the annular space as long as tar distils over below. The thick fluid swimming uppermost in the condensing vessels, which at first is yellowish-brown and at last blackish-brown, is the tar—a solution of pyroligneous resin in volatile oils, and acetic acid. If it is separated from the lower watery layer and distilled by itself, a mixture of these latter is obtained, pine-tar oil (Kienöl), and the resins remain as ship's-tar, or *pitch*, a more particular account of which product will be found below. According to Stolze, the foliaceous woods produce from 9 to 10, the coniferous woods 13 to 14 per cent of tar. A very good arrangement for obtaining both charcoal and tar is shown in Fig. 15. The space in which the wood is to be charred is an iron box (brickwork requiring too much fuel to heat), that will contain one, or at most, two stacks; it is placed over a grate, in such a manner that the flame shall pass in a spiral manner round its sides and into the chimney; *b* is the door for filling; the tube *c* carries off all the volatile products, first through the cooler *d*, whence the condensed products are conveyed to the receiver by the tube *e*, whilst by another tube *f* the gases pass to the fire-hearth.

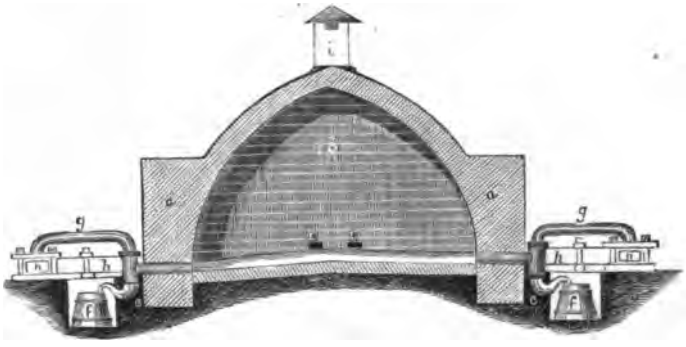
FIG. 15.



When the fire produced by the combustion of faggots at *g* has raised the box to a red-heat, the first vapours which appear carry with them combustible gases; as soon as these are produced in abundance, the cock at *v* is opened, and they are admitted to the fire, where they burn, and afford sufficient heat to finish the process without any additional fuel. After about sixteen hours, the fire is extinguished by shutting off the gases, the whole apparatus is allowed to cool, and the charcoal removed. It has already been mentioned, that furnaces, like the one here described, when compared with heaps, can only char small quantities at once; experiments have been made to overcome this difficulty by constructing larger boxes, and supplying them with heating pipes, so that the heat might be applied not only at the surface, but to the centre. If the heating is conducted in such a manner that the flame contains little or no excess of oxygen, the pipes may then be dispensed with, and a saving of fuel effected by carrying the ignited gases at once into the body of the charcoal. The furnaces introduced by Schwartz into Sweden are constructed upon this principle; they are large, close, walled spaces, into which on the one side, the flame from the hot gases is introduced from a hearth built for the purpose, and from the other issues the tar-pipe.

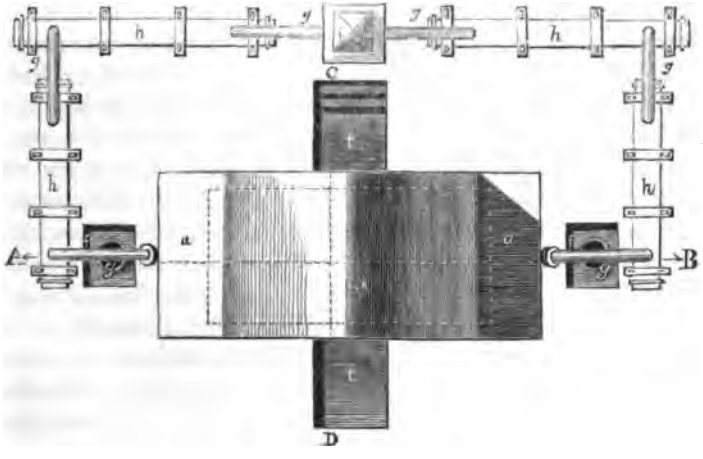
A longitudinal section of Schwartz's furnace is shown in Fig. 16, corresponding with the line *A B* of Fig. 17. The brickwork chamber *b* is 17 feet high, 27 feet long and 17 feet deep; the arch being 2 feet thick. The flames from a furnace situated on the outside enter by the apertures *c c*, which are about 15 inches in diameter and 2½ feet apart. Two similar apertures, leading from

FIG. 16.



another furnace, are situated on the opposite side of the kiln. The sole of the furnace is raised in the centre and inclines towards the sides, where two 15-inch pipes, connected with the bent pipes *e e*, are inserted, for carrying off the tar and other products of distillation. The tar which first condenses flows into the vessels *f f;* the more volatile acetic acid, wood-spirit, &c., are conveyed by the pipes *g g* to the condensing boxes *h h*, which are arranged at the back of the kiln and terminate in the chimney *i*, which is necessary to produce a draught through the entire apparatus. In Fig. 17, the arrangement of these

FIG. 17.



condensers is better seen; *t t* are two pits, whence the furnaces are supplied with fuel.

The arrangement of the fire-hearths is seen in Fig. 18 at *c*, they contain no grates, which would afford too much draught, and are bent in the form of a knee, to break the current of air. The apertures *dd* serve for charging the kiln with wood, and are bricked up during the firing. The walls must be perfectly sound and without cracks, nor must any lime, cement or mortar be employed about the interior of the kiln, where it would be exposed to the vapour of acetic acid.

FIG. 18.

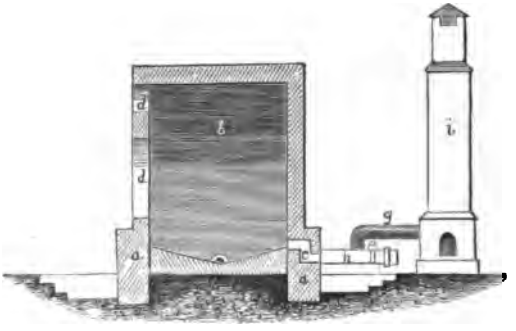


FIG. 19.

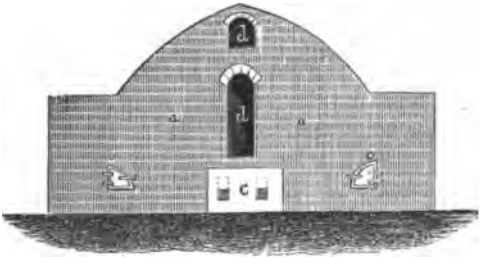


Fig. 19 is a front elevation of the kiln.

In working one of these kilns, the floor is laid with about two feet of light faggots, upon which the wood is piled as closely as possible, except in the immediate neighbourhood of the openings for the flame, where a space of a few cubic feet is left. During the whole period of charring, the fire-hearths must be kept filled with fuel, to prevent the ingress of air. When light blue smoke issues from the chimney, the process is finished, and the fire-hearths are closed up as completely as possible. In the course of a day or two, water is poured over the charcoal, from holes in the roof of the kiln, which is again repeated after some time; and when the metal pipes *e e* appear quite cold, the charcoal may be withdrawn without fear of rekindling. The quantity of fuel consumed is about 20 per cent of the quantity of wood charred.

As it is quite impossible totally to exclude the air from these furnaces, and under all circumstances some carbonic acid and much aqueous vapour must be produced from the combustion of the fuel, these gases, coming into contact with the red-hot charcoal, will necessarily reduce its quantity, and the produce is consequently not

found to exceed that obtained in the ordinary meiler. They have, however, one advantage over the meiler, which will always render them an economic auxiliary to that process, and this consists in the facility which they afford for charring wood of all shapes and sizes, and the pieces, such as roots, branches and unshapely logs, that are rejected by the charcoal-burner as ill-adapted for the construction of the meiler.

Many of these kilns are employed in Sweden, where much wood charcoal is still used for metallurgical processes, and are found to last for a long time. One furnace will produce about 2,700 cubic feet of charcoal per month, throughout the year; the first cost of the kiln amounts to about £35.

In other places it is found more economical to employ the waste heat from some other operation than that from a separate fire. Thus, the flame from blast furnaces has been employed with success for the purpose, several kilns being arranged round the mouth. Supposing these all to be filled with wood, the flame is conducted through a sliding-door into the first, until the heat is sufficient to complete the charring; the door is then closed, and the flame is conducted to the next, and so on. Before the charge in the last is completely charred, the first kiln has in the meantime been refilled.

Heated steam has been recently proposed as an agent for producing wood charcoal; but has only been practically employed in the manufacture of red charcoal, for the preparation of the superior kinds of gunpowder. The process will be noticed under the head of Gunpowder.

The Produce.—The produce in charcoal is apparently, at first sight, very variable. The experiments undertaken by Juncker, at the instigation of Berthier, at the smelting works in Poulaouen, are calculated to afford the most trustworthy results. The following woods, all thirty-two years old, were first weighed and then charred in similar heaps of five stacks each. The weight of the charcoal was ascertained immediately after its preparation, before it had had time to absorb aqueous vapour. Unfortunately, however, the quantity of water in the wood was not previously estimated. The following results were obtained:

Species of Wood.	Charcoal.	Half-charred Wood.
	per cent.	per cent.
Green red beech, cut in May, 1832	19.7	0.6
" " " " " without bark	23.0	0.3
Dry " and oak, 2 years old	24.0	0.3
Dry oak, 2 years old, without bark	25.7	0.34
Green oak, cut in May, 1832	22.4	0.3
" " " " without bark	21.2	
" " " " with bark	18.8	1.0
Equal parts of barkless red beech and oak, cut Jan. 1831, and carbonized in August, 1831	23.4	0.5
Green red beech, with bark, charred immediately	12.9	0.3
Green oak, immediately charred	13.5	0.4

The first five experiments were made in August, and consequently at a favourable season; the last five in January, when the weather was unfavourable. The mean produce of the whole series is 20 per cent. Beschoren obtained, at Eisleben, in meilers of 20 feet circumference, the following quantities:

	I.	II.
From Oak-wood (split-logs)	21.3	23.4 per cent.
" Red Beech "	22.7	— "
" Birch "	20.9	— "
" Beech "	20.6	— "
" Pine "	25.0	— "

Fr. Meyer obtained from five experiments on fir-wood logs, charred in meilers of 30 feet circumference, at Elend in the Hartz, 20.8, 21.2, 23.7, 21.7 and 27.5 per cent of the wood employed.

At Hiflau, in Styria, and at Görsdorf in Saxony, coniferous woods are found to yield 26 per cent. Af Uhr states the produce from five meilers, in Sweden, of 30 feet diameter, and 10 feet high, at 25.2, 20.7, 26.4, 20.0, and 28.0 per cent. Omitting the last two experiments of Berthier, the mean of these twenty-six experiments will give 23 per cent as the produce from the meiler. The mean produce from kilns is, according to Karsten's experiments, about 26 per cent; as, however, a quantity of wood is consumed in heating the kilns, amounting to about $\frac{1}{4}$ of the quantity charred, these twenty-six parts will in fact be the produce of one hundred and twenty parts of wood, and, therefore, only about 22 per cent in reality, being not so much as the average quantity produced in meilers. The erection and repair of the

furnaces entail some outlay, which very much exceeds that required for attendance on the meiler. None of the methods described produce more than ⅓ths of the whole amount of carbon contained in dry wood, so that there can be no doubt as to the inefficiency of all the processes. The wood, in the state in which it is employed, contains 20 per cent of hygroscopic moisture, 40 per cent of hydrogen and oxygen, and 40 per cent of carbon. The carbon is consumed during the process, in various ways; firstly, in evaporating water contained in the wood, and that which is formed by the union of oxygen and hydrogen; secondly, in producing, with portions of the other elements, tar and pyroligneous acid, &c.; thirdly, in evaporating these; fourthly, in producing a red heat throughout the mass of charcoal; and fifthly, in supplying the constant loss of heat: that which remains after a supply has been furnished for these different purposes is the *produce* in charcoal. If the whole of the hydrogen be supposed to unite with oxygen, without taking up any carbon, there will be $40+20=60$ per cent of water to evaporate; this, as will be shown below, will require 5½ per cent of charcoal; of the remaining 34.5 per cent, 0.6 will be consumed in bringing the whole to a red heat, and from 1 to 2 per cent will necessarily be uselessly burnt. Any method by which the remaining 32 per cent of charcoal could be obtained, must depend upon the hydrogen uniting exclusively with oxygen, without exerting any affinity for carbon; and as this would be contrary to the laws of chemical combination, no prospect is held out by science of its ever being attained. According to Stolze's experiments, the carbon contained in the tar and acetic acid amounts to 11 per cent of that contained in the wood. Statements, like those of Kavanko, according to which the Chinese obtain from 30 to 35 per cent of charcoal from fresh wood, or the entire amount of carbon, are absurd.

It is not unusual in many places to calculate the amount of produce by volume, in which case the unoccupied space left between the pieces of wood and of charcoal must be taken into the calculation, and this cannot be done with any degree of certainty. The gross volume of the wood (including the intersticial spaces) (1.) is sometimes compared with the gross volume of the charcoal; at other times the actual volume (deducting the intersticial spaces) (2.) is compared with the actual volume of

the charcoal; and again, the gross volume of the wood may be compared with the actual volume of the charcoal (3.)

The following observations have been recorded upon the (1.) mode of comparison:

	Produce.	Observers.
Fir and pine logs (Sweden) . . .	50.5—75 per cent.	af Uhr.
Pine logs (Hartz)	50. —70 „	
Split beech-wood	60.8—61.8 „	Pfort.

The mode of comparison (2.) yielded:

		Observers.
Pine logs, mean of five meiler experiments (Hartz)	47.6 per cent.	
Split pine logs (Saxony)	60.0 „	Lampadius.
„ „ „	69.5 „	Foy, Gruner, Harlé.

Beschoren obtained the following comparative results at Eisleben:

	By weight.	Compared according to method (I.)	Compared according to method (III.)
Oak-wood . . .	21.3 per cent.	71.8 per cent.	98.7 per cent.
Ditto	23.4 „	74.3 „	102.0 „
Red Beech-wood .	22.7 „	73.0 „	100.4 „
Birch „ .	20.9 „	68.5 „	94.2 „
White Beech „ .	20.6 „	57.2 „	78.6 „
Scotch Fir „ .	25.0 „	63.6 „	87.2 „

Any estimation of the produce in charcoal by volume is subject to the great objection that the most porous pieces, and such as are full of cracks, count equally with the denser and more compact.

Properties of Wood Charcoal.—Wood charcoal is a substance that varies very considerably in composition and properties with the source or kind of wood from whence it is derived, and with the degree of temperature to which the wood has been submitted in the process of manufacture. As prepared on a manufacturing scale by the processes already described, it never consists of pure carbon, but always retains some volatile ingredients, which can be driven out by a strong and continued red heat, as well as the ash that is contained in the original wood, to which hygroscopic water must be added, if the charcoal has been some time prepared. All the varieties of charcoal may be conveniently classed under the heads of *hard* and *soft* charcoal. The former being derived from the hard close-grained woods, such as oak, beech, &c., while the soft foliaceous and coniferous woods afford *soft* charcoal. Another

and more important distinction arises from the temperature employed in the manufacture, upon which the amount of volatile ingredients depends. Highly charred wood is called from its colour *black* charcoal, while that prepared at a lower temperature goes by the name of *red* charcoal, or *charbon roux*, the preparation of which will presently be described.

Good black charcoal is very dark in colour, of a bright lustre, and somewhat conchoidal fracture; when allowed to fall upon a hard surface it produces a sharp sonorous noise, withstands a gradual pressure to a considerable extent, but is easily broken in pieces by a sudden blow; it soils the fingers but little, and the dust is easily removed. Charcoal swims on the surface of water. Ignited, it should burn without flame or smoke. Bad charcoal soils the fingers, is not sonorous, and burns with smoke and flame. A remarkable property of charcoal is its power of absorbing gases into its pores, more particularly those which are easily liquified, as ammoniacal gas, hydrochloric, hydrosulphuric and carbonic acids. Of the first it will absorb 90 times its volume and 35 times its volume of the last; of oxygen it condenses 9.25; of nitrogen 7.5, and of hydrogen 1.75 times its volume. It also condenses aqueous and offensive vapours from the atmosphere, on which account it is sometimes employed to remove the unpleasant odours from clothes, and it also retards putrefaction when brought into contact with matters undergoing decay. The amount of water absorbed by different varieties of charcoal appears to be dependent upon their degrees of porosity and the length of time during which they are exposed. According to Nau's experiments the freshly-prepared black charcoal from different woods will absorb during the first twenty-four hours after preparation quantities of water varying from 0.8 to 16.3 per cent of its weight, as is shown in the following table:

	Amount of water absorbed in twenty-four hours.
White Beech charcoal	0.80 per cent.
Ash "	4.06 "
Oak "	4.28 "
Birch "	4.40 "
Larch "	4.50 "
Maple "	4.80 "
Pine "	5.14 "

	Amount of water absorbed in twenty-four hours.
Red Beech charcoal.	5.30 per cent.
Horse-chesnut „	6.06 „
Elm „	6.60 „
Alder „	7.93 „
Scotch Fir „	8.20 „
Willow „	8.20 „
Italian Poplar „	8.50 „
Fir „	8.90 „
Black Poplar „	16.30 „

The effect of longer exposure to the atmosphere upon the quantity of water absorbed by charcoal is shown by the following results obtained by Werlisch.

100 parts of birch-wood charcoal weighed:

On the 24th of June	100
„ 30th „ „	104.35
„ 7th „ July	105.63
„ 16th „ „	106.57
„ 29th „ „	107.62
„ 20th „ August	108.16
„ 17th „ September	108.44

The charcoal employed for these experiments was taken some time after it had been burned, and not quite fresh from the meiler, so that in all probability it contained about 4 per cent of moisture, or the quantity which birch-wood charcoal is shown in the first table to absorb in twenty-four hours, and the total quantity taken up in eighty-five days would be not less than 10 or 12 per cent. In moist weather this would be absorbed in less time, and probably increased in quantity. From these results it appears difficult to form an estimate of the actual quantity of water absorbed by charcoal, but about 12 per cent may be safely assumed as an average. Berzelius estimates it at from 10 to 20 per cent.

Ash.—The amount of ash contained in charcoal is dependent upon the kind of wood employed in its manufacture. From 100 parts of wood (containing 20 per cent of moisture) an average amount of 20 parts of charcoal is obtained, so that the quantity of ash contained in it must be five times as great as that in the wood. The average quantity of ash in wood varies between $\frac{1}{2}$ and 1 per cent, and the charcoal should consequently contain about

3 per cent. Winkler found in general a lesser quantity, as is shown in the following table:

	Amount of Ash.
Lime-wood charcoal	3.55 per cent.
Maple „ „	2.27 „
Ash „ „	2.27 „
Elm „ „	2.17 „
Willow „ „	1.50 „
Fir „ „	1.44 „
Pine „ „	1.38 „
Poplar „ „	1.30 „
Beech „ „	1.25 „
Scotch Fir-wood „	1.11 „
Birch „ „	0.80 „
Oak „ „	0.75 „

These twelve results only yield a mean of 1.65 per cent. Other kinds have been found, however, containing as much as 5, and even nearly 10 per cent of ash.

The specific gravity of the different varieties varies very considerably, and is of importance in their application as fuel. The very accurate experiments of Hassenfratz yielded the following results:

	Specific Gravity.
Birch-wood charcoal	0.203
Ash „ „	0.200
Wild Service-wood charcoal	0.196
Red Beech „ „	0.187
White Beech „ „	0.183
Elm „ „	0.180
Red Fir „ „	0.176
Maple „ „	0.164
Oak „ „	0.155
Pear „ „	0.152
Alder „ „	0.134
Lime „ „	0.106

The following statements are the mean of numerous observations made upon a large scale:

1 cubic foot of beech-wood charcoal					(split logs)	interstices included,			weighed	8 to 9 lbs.
1	„	„	„	„	(brushwood)	„	„	„	7	to 7.5 „
1	„	„	„ oak	„	(split wood)	„	„	„	7	to 8 „
1	„	„	„ „	„	(brushwood)	„	„	„	6	to 6.5 „
1	„	„	„ soft-wood	„	of different kinds	„	„	„	4.5	to 5.5 „
1	„	„	„ pine-wood	„		„	„	„	5.5	to 7. „

It is a remarkable circumstance that a preference is given by consumers to charcoal that has been stored for some time and absorbed moisture, and more actual heat is said to be derived from it in that state than when freshly prepared. If this be really the fact, it is at present inexplicable.

When charcoal is stored in large heaps it becomes crushed, and much is reduced to powder, in which state it is useless as fuel, sufficient air not being accessible to enable it to burn. As much as from 12 to 16 per cent is often sacrificed when the charcoal has to be carried to any distance. A new process for working up this refuse dust will be noticed below.

Black charcoal is a very bad conductor of heat, and requires a high temperature for ignition; once ignited and amply supplied with air, it burns easily. The highest degree of combustibility is developed in the charcoal which has been reduced to powder in revolving drums with metallic balls, as employed in the powder factories. So great is it, indeed, that sometimes spontaneous combustion occurs, which may perhaps be accounted for by the heat generated by the condensation of air in the porous charcoal rising sufficiently high to enable the particles of carbon to exert their affinity for oxygen.

The average composition of black charcoal may be stated as follows:

	Fresh.	Old.
Carbon . . .	97	85
Ash . . .	3	3
Hygroscopic Water .	0	12
	100	100

RED CHARCOAL—CHARBON ROUX (ROTHKOHLE.)

It has already been stated, that the object of charring wood is to increase the amount of combustible matter per volume. Thus, a cubic foot of beech-wood, weighing 20 lbs., contains,

after the abstraction of its hydrogen and oxygen, nearly 9 lbs. of combustible matter; a cubic foot of beech-wood charcoal, on the contrary, contains no other ingredient, and weighs 12 lbs. We have, therefore, increased its combustible matter ⅓ per cubic foot, and yet it is by no means essential that the carbonization be perfect, as is the case in charcoal from the meiler process, in order to obtain this result. Berthier pointed out this fact some years ago, and Sauvage has now proved it by a series of interesting experiments. Sauvage charred 5 equal parts of air-dried wood, in the same furnace, one after the other, and interrupted the process each time at a different interval, in order to examine the products of the various degrees of carbonization, as to their loss of weight and bulk, and their amount of combustible matter. He found that:

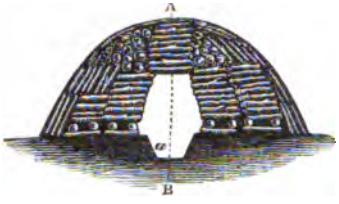
100 lbs. wood charred for	3 hours.	4 hours.	5 hours.	5½ hours.	6½ hours.	Mound charcoal.
weighed . . .	65.4 lbs.	53 lbs.	47 lbs.	41.5 lbs.	39.1 lbs.	17.2 lbs.
and 100 C. F. measured	86 C. F.	76 C. F.	58 C. F.	55 C. F.	52 C. F.	33 C. F.

lastly, they contained of combustible matter:

1 C. F. wood		908	parts by weight.
1 „ „ charred during 3 hours		883	„ „
1 „ „ „ „ 4 „		904	„ „
1 „ „ „ „ 5 „		1133	„ „
1 „ „ „ „ 5½ „		1091	„ „
1 „ „ „ „ 6½ „		1136	„ „
1 „ meiler charcoal . . .		1069	„ „

It is evident, from this table, that the amount of combustible matter in equal volumes of charred wood, does not increase even after exposure to heat for 5½ hours, that a continuance of the heat beyond that time occasions an absolute loss, and that it must be advantageous to stop the process before the formation of black meiler-charcoal is effected, a practice which is already becoming general. Wood imperfectly charred, so as to leave in the product the maximum quantity of combustible matter per volume, is called *red charcoal* (*charbon roux*). In France and Belgium, where this new kind of charcoal is in use, it is prepared by a kind of meiler carbonization. The meiler is more in the shape of a pile, lengthened out, and erected over a channel *a* formed in the ground, Figs. 20 and 21.

FIG. 20.



The heated gases of a fire, situated at one end at *P*, Fig. 21, are forced by the motion of a fan *v*, to pass along the channel *r* into *a*, whence they permeate the whole mass of the wood, which thus heated, undergoes dry

FIG. 21.

distillation. On the outside, the heap is covered with a layer of earth, through which the gases are allowed to escape at those parts to which it is desirable to direct the heat. The operation is, therefore, regulated in the same manner as in the meiler with moveable covering. The results obtained by Sauvage upon this plan have not been satisfactory, the wood was either insufficiently charred, in fact, not more than kiln-dried, or when more heat was applied the wood was ignited. The waste gases from smelting or blast-furnaces have also been employed in the manufacture of red charcoal, but with no better success. Experience and practice may possibly enable the furnace charring of Schwartz to be so modified as to afford red charcoal of uniform quality, but it appears difficult to adapt Schwartz's principle to meiler carbonization. The introduction of *charbon roux* into a country is of importance, as it effects a great saving in the consumption of wood, the scarcity of which is always on the increase. The great difficulty appears to be in producing red charcoal of uniform quality in large quantities at once. Heated steam has been employed by Thomas and Laurent, and, according to Heyss, de la Croix has employed a patent process, both in Belgium and Austria, for charring wood, turf and coal by means of heated steam. Violette appears to have prepared excellent red charcoal for the powder manufacture by this means. Whether, however, the expense of transporting all the wood to a stationary boiler

in the neighbourhood of the consumption will not be too great when the charcoal is to be used as fuel appears questionable. Violette's process will be described under Gunpowder.

The produce of red charcoal depends entirely upon the degree of heat employed in the carbonization. The red charcoal prepared by heated steam for gunpowder-making at a temperature of 300° C. (572° F.) was found to vary from 36 to 42 per cent of the air-dried wood, according as it was exposed from one to three hours to the heat in the cylinders. Much of the hydrogen and oxygen of the wood are retained by the red charcoal, and assuming kiln-dried wood as composed of 50 per cent of carbon and 50 per cent of water, red charcoal will probably contain about 75 per cent of carbon and 25 per cent of oxygen and hydrogen, although these latter are no longer in the relative proportions in which they unite to form water.

The amount of ash is less in red than in black charcoal, a larger quantity of charcoal being obtained from the same weight of wood. The mean quantity is estimated at 1.5 per cent. Red-charcoal being less porous, does not absorb water from the atmosphere with the same avidity as black, and no experiments have been recorded upon the actual quantity contained in it. Freshly-prepared red charcoal ignites much more readily than black, in consequence of the volatile combustible matters it contains; it produces a long, powerful, and luminous flame, but not equal to that of kiln-dried wood.

From the very variable nature of red charcoal, it is difficult to arrive at any accurate knowledge of the composition of different qualities; but the following may be assumed as the average composition:

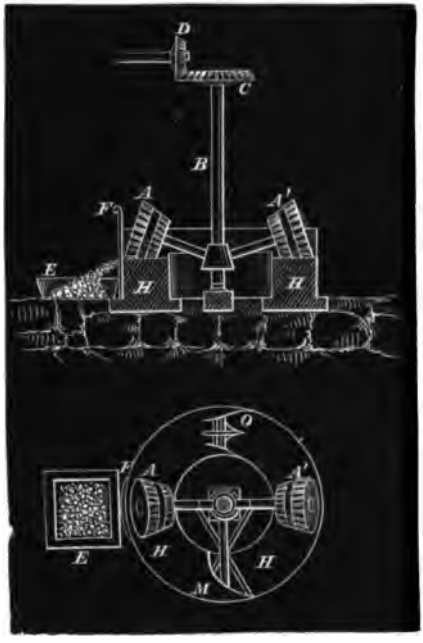
	Fresh.	Old.
Carbon	74	66.5
Oxygen and Hydrogen .	24.5	22.0
Ash	1.5	1.5
Hygroscopic Water . .	0.0	10.0
	100.0	100.0

Moulded Vegetable Charcoal.—The manufacture of vegetable charcoal in moulds is a branch of industry which has attracted some attention in France within the last two years: one manufactory producing upwards of 2,000 tons per annum in Paris.

The raw materials, so to speak, consist of the waste powder

from wood charcoal, peat charcoal, twigs, brushwood, charred tan, &c., and tar or liquid pitch.

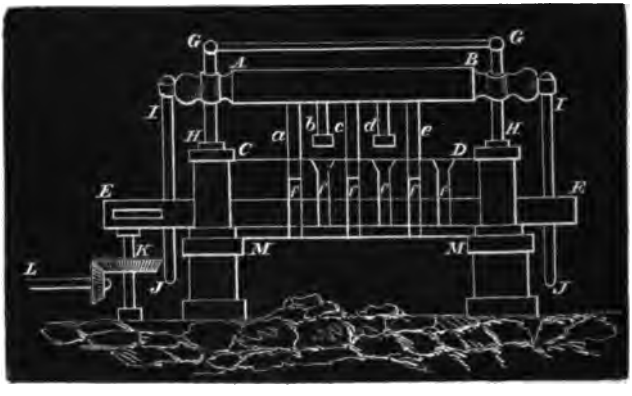
FIG. 22.



The whole is reduced to a coarse powder between fluted iron rollers, and then thrown on the bed-plate (*H H*, Fig. 22) of a mill, working with a pair of conical fluted stones *A A*, made of cast-iron. The upright shaft *B* is driven by the pinion *D* working into the mitre-wheel *C*. A scraper *O* follows the stones in the usual manner; 7 to 9 gallons of tar are added to about 2 cwts. of charcoal-powder, which are intimately mixed by the stones, and become a thick, homogeneous paste, which is discharged at the slide *F* by the scraper *M* into a box at *E*. This mill requires one-horse power, and prepares from 6 to 7,000 gallons per twenty-four hours.

The paste is moulded by the machine shown in Fig. 23. A

FIG. 23.



strong wooden beam is raised and lowered alternately by an eccentric motion communicated to the rods *I J, I' J'*. Two collars

which slide upon two iron uprights *H G*, and *H′ G′*, guide the beam *A B*. The iron pistons *a b c d e* of unequal length are firmly attached to the beam *AB*.

Two women are constantly employed filling the funnels *f f f* with the paste, which is pressed into the moulds by the pistons *b d*, while the horizontal movement communicated to the metal casting *E E* as shown at *L K* immediately carries the full cylinders under the pistons *a c e*, which expel the moulded paste, and thus the operation proceeds continuously.

FIG. 24.

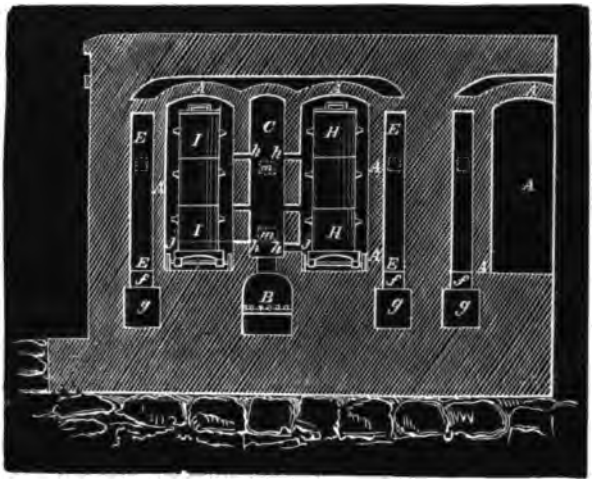
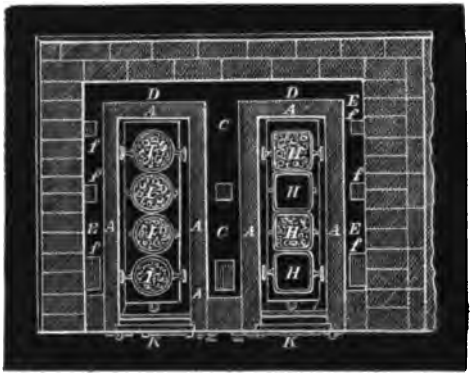


FIG. 25.

The power required to work this machine is equivalent to that of six horses, and it employs one man and four women, who make about 450 bushels of these cylinders per day.

The cylinders are air-dried for thirty-six to forty-eight hours before being exposed to carbonization, which is conducted

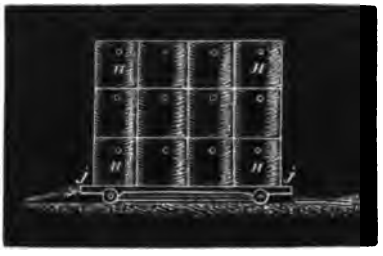
FIG. 26.



in a muffle furnace as shown in Figs. 24, 25, and 26. The muffles *A A* about 4¼ inches thick, must be strongly built, and are heated by a fire at *B*. The flame heats the muffles all round, passes behind them through flues *C D*, returns in front by *E*, and finally passes off by the openings *f f* through the underground flues *g g g* to a high chimney at the back.

The dry-moulded cylinders, 4½ inches long by 1½ inches diameter, are ranged in two layers in sheet-iron boxes *H H*, or cast-iron cylinders *I I*, and the whole placed on trucks *j j*, Fig. 27, which are then run into the muffles. A metal door *K* (Fig. 25), lined with brick and luted with clay, encloses the whole till the carbonization is complete.

FIG. 27.

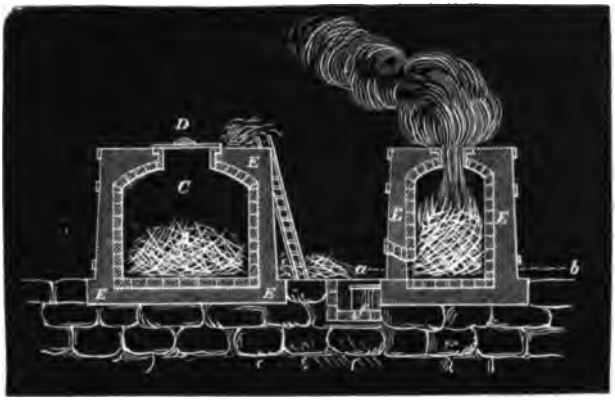


The moisture remaining in the moulds, and the carburetted hydrogens produced by the increasing heat, make their escape through the small flues *h h*, and after the lapse of a certain time, when the cylinders have become red hot, a small current of air cautiously admitted at *m m* ignites these gases. The heat thus produced is sufficient to finish the operation. Two muffles are charged every six hours, and each muffle is filled twice in the twenty-four hours.

The cylinders are withdrawn as soon as the flame ceases to appear, which the workman ascertains by opening the air-flue *m*.

The waste cuttings and brushwood which are not adapted for the plan described above, are converted into common charcoal in furnaces shown in Fig. 28, constructed, like coke ovens, of a strong outer wall *E* with an opening *C* at the top, and another at *A* at the level of the floor. The charcoal is drawn into a pit *f* filled with water. The wood *A* is thrown in by degrees, and drawn every seven hours, or as soon as a flame appears at *C*, which

FIG. 28.



is then immediately made tight by an iron plate *D*. Each furnace produces about 8 cwts. of charcoal per twenty-four hours from about 26 cwts. of wood.

The moulded charcoal being more dense than that made by the old plan, is found useful for domestic purposes—it burns longer, and does not lose so much heat by radiation. It is most serviceable in the laboratory, especially for organic analysis.

PEAT CHARCOAL.

Preparation of Peat Charcoal.—Two circumstances are very favourable to the charring of peat in the meiler; first, the rectangular form of the peat bricks, which admits of their being piled up together without leaving those interstices so prejudicial in the wood meiler; and second, the lesser combustibility of peat charcoal renders such minute attention to the process unnecessary, and admits of the construction of meiler very much less in circumference, with advantage.

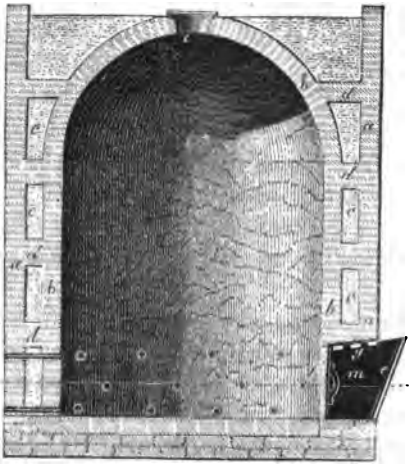
The peat bricks for charring are often cut somewhat larger than those used commonly as fuel, and of these from 5,000 to 6,000 constitute a meiler, the dimensions of which seldom exceeds 10 feet in circumference, containing altogether about 1,500 cubic feet. The stake or quandel is erected on a dry spot, and round it the turf-bricks are ranged endwise in concentric circles, diminishing in number as the height increases, so as to give a hemispherical form to the meiler; air-channels, radiating from the centre, of the width of a single brick, being left in all directions to admit air to the interior, which, from the close manner in which the turf

packs would not otherwise be accessible. At the foot of the stake some dry wood is placed for ignition; the meiler is covered with an inner coating of moss and leaves, and with an outer one of earth or charcoal dust, leaving only the middle part of the hood round the stake uncovered, for the passage of the gases, after the meiler is ignited by one of the open channels. By opening and closing these channels, the combustion is conducted in all directions until flame appears at the aperture in the hood, which is then closed, while holes are pierced all round the covering, consecutively, from the top to the bottom, at distances of a foot apart, until the charring is completed. The appearance of the smoke issuing from these apertures indicates the stage and state of the operation, which must vary in its management with the age, density and other physical properties of the peat.

The produce from the mounds has been found as follows: from not quite air-dried peat, 24 per cent of the weight and 27 of the bulk have been obtained; from air-dried, 27 per cent in weight, and 32½ in volume; from freshly-dug Pfungstädt peat, 30 per cent in weight, and 29 in bulk; from excellent peat, quite dry 35½ of the weight and 49 per cent of the bulk. In the district of Siegen very good peat produced 23 per cent of the weight and 40 per cent of the bulk. Experiments upon a small scale generally afford a still larger produce, sometimes as much as 40 per cent of the weight. Some difficulty is found in extinguishing the peat meiler; a thin paste of clay and water is found serviceable in accelerating it. The peat charcoal is very apt to fall to powder, in which state it is useless as fuel.

Peat Charcoal Kilns.—The use of kilns affords no increase of produce, but a safer regulation of the heat, and is better adapted to peat than to wood, as that substance is always obtained upon the same spot, and it is not necessary, as in the forest, to follow the clearing or to transport the material. In the manufactory of arms at Oberndorf in Würtemberg, kilns are employed which have stood the test of five years' experience, and have been approved; one of these is represented in Fig. 29. It is in the form of an upright cylinder, 9 feet in height, and 5½ feet in diameter, closed at the top by a circular arch, and with a capacity of about 200 cubic feet. The kiln itself *b* is surrounded by a second wall *aa*, in such a manner as to leave a space *cc*, which is filled with sand, to prevent loss of heat by conduction. Both walls are of brick, each 15 inches thick, the space *cc* being of the same dimensions, so that the

FIG. 29.



entire thickness of the walls is 45 inches. *d d* are stones, placed longitudinally and perpendicularly, to give greater solidity to the walls. Above the sole of the furnace are three rows of draught holes, formed of pieces of old gun barrels walled in, which can be readily closed. The door for withdrawing the charcoal is closed by the cast-iron slab *f;* the iron support of the door projects slightly forward and in front of it is a deal board *e*, the space *m* being filled with sand from *g*. A space is left in the centre of the kiln for igniting the contents. In the beginning, the aperture *i*, through which the charge of peat is introduced, and the lower draught holes, are left open, and as soon as the peat, when viewed through these, appears white hot they are closed, and the upper ones opened. When no more smoke is visible the apertures are all stopped, or filled with sand, and a layer of sand about one foot thick is covered over the aperture *i;* this takes place in about forty to forty-eight hours, and the kiln is then left to cool during six or seven days. In order to save time water is sometimes poured upon the charcoal from the aperture *i*. Ten of these furnaces are worked at the same time, in order to afford a constant supply of charcoal.

Peat charcoal, as far as heating power is concerned, ranks among the best kinds of fuel; it possesses, however, at the same time, qualities which render it unfit for many purposes. If 100 lbs. of dry peat leave 21 lbs. of ash, and produce 47 lbs. of charcoal, these 47 lbs. of peat charcoal will contain 21 lbs. of ash, or 45 per cent, which large amount must interfere in many of its applications from its mere bulk, and in others from the tendency it has to fuse and combine chemically with the substances heated in contact with it: while the phosphates and sulphates it contains are objectionable in many metallurgical processes. Those varieties of peat which contain a large amount of ash are, consequently, quite unsuited to the

manufacture of charcoal. Another great objection to peat charcoal, is its loose brittle character which soon causes it to fall to pieces, and become useless; in smelting furnaces the pressure of the layers of ore suffices to crush it to powder, in which state it so materially obstructs the blast as to derange the entire process; its application is, therefore, confined to boilers, evaporating pans, forge fires, and domestic purposes, while even for such it is inferior to kiln-dried peat. The want of firmness has been found to render this charcoal quite incapable of bearing carriage, and the carbonization must, therefore, be effected on the spot where the charcoal is to be used.

Stones has patented a process for compressing peat in boxes, between rollers in such a manner as to afford hard, square bricks, which are afterwards heated in retorts of wrought-iron, similar, in size and shape to those used in the manufacture of illuminating gas, with an apparatus for condensing the products of the distillation in a series of receivers so as to separate them to a certain extent without a second distillation; the combustible gases being employed as fuel for heating the retorts.*

Vignoles employs steam, heated to 450° or 460° F., which is between the melting-point of tin and lead, for charring peat in upright cylinders; the peat having been previously dried, either by a current of hot air produced by a fan driven by the waste steam from the apparatus, or by a hydro-extracter in which centrifugal force is employed to expel the moisture.

FIG. 30.

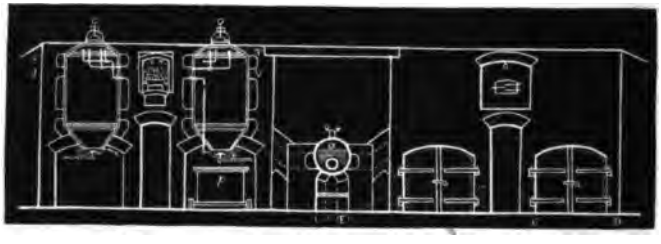


Fig. 30 represents a vertical section and partial elevation of the apparatus. *a* represents a section of the large cylindrical steam boiler set over a furnace, the flues from which pass round the cylindrical carbonizing vessels, two of which are shown in the drawing to the left of the boiler, and of which there are six on

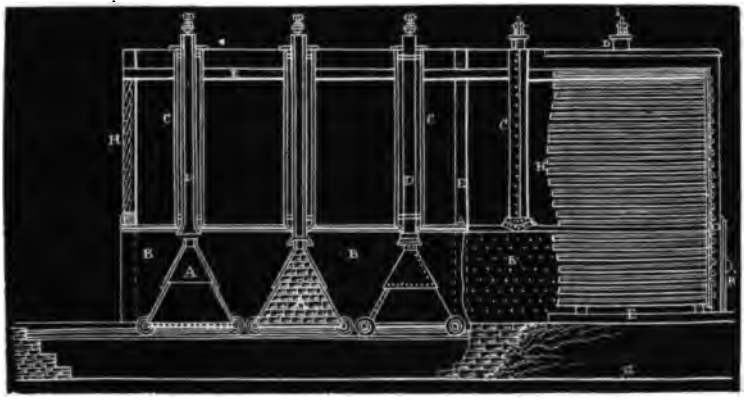
* Rep. Pat. Invention, XVII, 16; XIX, 220.

each side, arranged round a central coil of pipes *H*, in which the steam from the boiler *a* can be heated to the required temperature before its admission to the carbonizing vessels. The steam having passed from the boiler through one department of the red-hot coil, is conveyed into one of the carbonizing vessels; whence, having sufficiently charred the peat, it passes through another part of the coil into the next, and so on, until having passed through all six it is employed to work a low-pressure engine, which drives a fan, the current of air from which is heated, by passing through pipes, to 250° F., before it is admitted into chambers where the moist peat is exposed to dry.

The cylindrical carbonizing vessels are composed of boiler-plate, conical at bottom, where they are furnished with a steam-tight man-lid or door for the emission of the charred peat, a similar door being fixed in the dome-shaped upper part for its introduction. The charred peat if exposed to the air would be liable to spontaneous combustion, it is discharged, therefore, into iron cooling-boxes *p* placed below the carbonizing cylinders, and low-pressure steam is blown once or twice through it.

Rogers has carried out a system of drying and charring peat in Ireland, the principle of which will be seen by reference to Fig. 31.

FIG. 31.

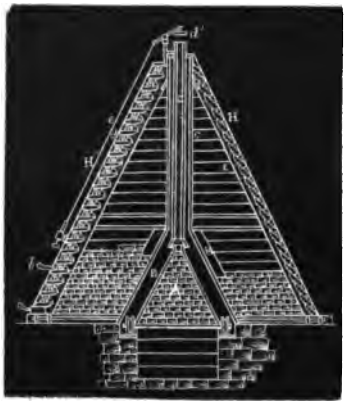


A long shed, shown in longitudinal section *E E*, is constructed over a sunk channel or ash-pit, traversing its entire length and built with bricks, on the margin of which a railway is laid down to enable small travelling chambers or kilns *A* to travel easily through the shed and over the ash-pit.

The kilns *A* are made of sheet-iron on a framework of iron with

wheels, the bottoms being constructed of bars which serve as a grate. They are filled with the peat to be charred by inverting them, and then inserting the grate. The interior part of the shed through which these travelling ovens pass is formed into a kind of chamber by sheet-iron plates *B B*, through which, at regular intervals, are pipes *D D* leading to the top of the shed. Within these vertical pipes are placed other moveable pipes which fit on to the tops of the kilns and perform the part of chimneys; they can be moved up and down sufficiently to admit the upper part of the kilns to pass below them. The sides of the shed are filled up with lattice-work shelves for the reception of the air-dried turf-bricks, and the slanting sides are protected from the rain by moveable louvres *H H*, which can be opened or closed at pleasure, and when supported by a few sods of turf below, serve as stepping-places for the workmen when employed in filling or emptying the shed. When the shed is packed, and the kilns are filled with turf and arranged under their respective chimneys, these latter are opened at *d* by the rod *e*, and the turf is ignited from below by the ash-pit. The charring is then carried on as in other furnaces of similar construction, a portion of the turf being consumed in charring the remainder and the draught is regulated by the flue-door at *d* and the ash-pit door below. The heat from the kilns is thus made to dry the turf in the shed, and its action is sometimes augmented by a current of air forced through the house by a fan.

FIG. 32.



Green produces a hot draught of air through a drying-house by means of chimneys and fires, and then distils the dried peat in wrought-iron cylinders placed two over a furnace, and similar to those employed in making illuminating gas, the gases from the turf being consumed as part of the fuel below the retorts.

LIGNITE CHARCOAL.

Of all kinds of fuel, brown coal, or lignite, is least adapted for carbonization, although it is decomposed with as much ease as wood, and the charcoal which it produces is not so easily inflam-

mable. The previous remarks on the ash of peat apply with equal force to brown coal, but even the best kinds of brown coal are not easily charred, for during the action of the heat, the single layers, concentric rings, &c., which are scarcely perceptible in the fresh specimens, split off, and a compact piece of brown coal becomes thus completely broken up into small fragments, or so fissured as not to bear carriage. Roschers states that lignite, if thoroughly air-dried when fresh from the pit and very slowly charred, is not subject to this disintegration; and, according to Mayer, very firm charcoal is obtained by charring the freshly-dug lignite without previously exposing it to the air. In experiments with lignite from the Hessenbrücker Hammer (in the Wetterau), 15½ per cent by weight, and 32 per cent by volume were obtained by meiler carbonization. This quantity is too small to pay for the cost of manufacture.* In the neighbourhood of Cassel, where circumstances are more favourable, the carbonization in mounds is actually carried out, but only upon a small scale.

Experiments made with brown coal upon a small scale, in which the coal was heated in close crucibles, until all vapours ceased to be evolved, gave the following results:

	100 parts.	Charcoal. %
Left side of the Rhine, near Düren.	Earthy coal from Dax	49.1
	„ „ Bouch. d. R.	41.1
	„ „ Basses-Alpes	48.5
	Lignite from Greece	38.9
	„ „ Cologne	36.1
	„ „ Iceland	57.5
	„ „ Raddergrube	41.6
	„ „ „	49.7
	„ „ Gr. Urwelt.	44.3
	„ „ „	43.9
	„ „ „	51.3
	„ „ Friesdorf	28.2
	„ „ „	48.2
	„ „ „	46.8
	Earthy „ Uttweiler	68.2
	„ „ Raddergrube	48.3
	„ „ „	46.4
Right side, near Bonn.	Lignite from Pützchen	46.4
	„ „ „	44.7
	„ „ „	51.0
	„ „ Stösschen	29.1
	„ „ „	40.6
	„ „ Orsberg	62.8
	„ „ „	68.4
Bohemia.	„ „ Aussig	40.1
	„ „ „	40.0
	„ „ Hegendorf	41.2
Bohemia.	Lignite from Neundorf	38.4
	„ „ Coulang	38.1
	„ „ Jahnsdorf	32.8
	„ „ Paredel 1.	39.6
	„ „ „ 2.	40.7
	„ „ „ 3.	42.0
	„ „ Antoni-Zeche	40.0
	„ „ Wellonitzer Br.	35.9
	„ „ Nemtschauer Br.	34.7
	„ „ Hartenberg 1.	37.2
	„ „ „ 2.	34.6
	„ „ Kanden	37.5
	Pitch coal from Grünlat	37.2
	Earthy coal fr. Hartenberg 1.	42.1
	„ „ „ 2.	48.4
	„ „ „ 3.	36.8
	„ „ „ 4.	39.0
	Pitch „ „ 1.	43.9
	„ „ „ 2.	40.3
	Earthy coal from Soaz	46.4
	Pitch coal from Reichenau	38.1
	„ „ „	29.3
	„ „ Altsattel	40.3
	„ „ „	35.0
Bavarian Oberpfalz.	Earthy coal from Verau.	35.6
	Lignite „ „	46.0

* A cwt. of coal costs 5½*d.*, one cwt. of charred coal about 3*s.* 11*d.*

CARBONIZATION OF PIT COAL.

General Principles.—The products resulting from the charring of coal, although similar in kind, differ considerably from those obtained under the same circumstances from wood. This might reasonably be anticipated, from the different elementary composition of the two substances, the dissimilar arrangement of their elements, with the addition of nitrogen and sulphur (contained in pyrites), and the higher temperature required to complete the carbonization. The nature of the products very much depends upon this latter circumstance, or the degree of temperature employed. In addition to the solid coke as residue, both liquid and gaseous compounds are produced; the former being distinguished into an aqueous and oily portion, the latter containing many of the compounds found in wood-tar, but also numerous other bodies, which we shall notice in another place. As a general example of the products of the dry distillation of coal and their relative quantities, the following analysis, in which a slow distillation was pursued in a close vessel, may be adduced:

	Coke	68.925	
Liquid products.	Tar	12.230	=19.799
	Water	7.569	
Gaseous products.	Light carburetted Hydrogen (CH_2)	7.021	=11.276
	Carbonic Oxide	1.135	
	Carbonic Acid	1.073	
	Olefiant gas (C_2H_2)	0.753	
	Sulphuretted Hydrogen	0.549	
	Hydrogen	0.499	
	Ammonia	0.211	
	Nitrogen	0.035	
		100.000	

The relative quantities of these products, as well as the nature of the tar and water, vary with the temperature employed. When the charring goes on with the access of air, a portion of the coke as well as of the gaseous products of distillation is consumed in carbonizing the remainder.

The residue, after the action of heat upon pit coal, is commonly called *coke*. Coals may be subdivided with reference to the production of coke into two classes, the *coking* and *non-coking*; the

small of the latter are useless, unless mixed by mechanical means in certain proportions with the small of the coking coal, as has been proposed by Mr. Budd.

On the continent, those who have examined coal with reference to the property of coking prefer to classify it under the heads of *caking, sinter,* and *sand coal;* for the latter two denominations we know of no corresponding terms in English.

Caking or coking coal is that variety which, when strongly heated, undergoes a kind of semi-fusion while parting with its volatile ingredients, the separate pieces caking together to form one solid mass.

Sinter coal approaches nearest to caking coal, but the fusion of the separate pieces into one is not so perfect.

Sand coal produces coke that retains the form of the original coal without caking.

These varieties are distinguished from each other and from anthracite by their elementary composition, upon which indeed their coking properties very much depend, as will be seen by the following table, which shows the mean composition of the organic portion of the varieties of foreign coal, the analyses of which were given on a former page, arranged according to the above classification:

	Carbon.	Hydrogen.	Oxygen.
Sand Coal . . .	77	5	18
Sinter Coal . .	83	5	12
Caking Coal . .	87	5	8
Anthracite . .	95	3	2

It will be observed that the amount of hydrogen in the first three varieties is identical, while the oxygen diminishes as the property of caking is developed; but this is lost when both oxygen and hydrogen are very much diminished. But an excess of hydrogen which has been supposed by some to be chiefly instrumental in imparting the caking property to coal, is not alone sufficient to account for this property in all cases, as will be more clearly seen by some analyses of Regnault made expressly to determine this point, and in which great attention was paid to the character of the coke obtained from each variety of coal. The analyses alluded to have been given in detail in the former tables; we have here calculated

formulæ from them, assuming the same quantity of carbon in each in order to show the relation of the other elements more distinctly.

		Relation of H to O.
Anthracite from Balduc, sand coal . . .	=80 C + 44 H + O	14 : 1
Coal from Blanzy, sinter coal	=80 C + 64 H + 6 O	10.7 : 1
Cannel coal from Lancashire, sinter coal . .	=80 C + 64 H + 3 O	21 : 1
Coal from Mons (flenû) caking coal . . .	=80 C + 120 H + 5 O	24 : 1
Coal from Grand Croix (maréchal) highly caking .	=80 C + 56 H + 3 O	18.7 : 1

It will be seen that the property of caking generally increases with the quantity of hydrogen and oxygen, particularly with that of the hydrogen. Anthracite, consisting almost entirely of carbon, may be viewed as a kind of natural coke; the quantity of hydrogen rises in the others in proportion as they soften in the fire, with the exception of the last, which possesses this property in the highest degree, although its hydrogen amounts to only half the quantity contained in the caking coal from Mons.

The same fact has been remarked with the younger coal of Obernkirchen, which is also of a highly caking character. It also produces a porous, friable coke, and has the composition 80 C + 52 H + 3 O or O : H = 1 : 17. An explanation of this property of the coal can, therefore, only be expected from an investigation of its constitution, or the arrangement of its elementary molecules, a subject upon which science has thrown no light. The proportion and nature of the ash left by the coal has also some influence upon the caking property, as will be again adverted to in describing the manufacture of coke.

The foregoing remarks are also quite opposed to the observations on our English coal. The Scotch gas coals, for example, yield little or no coke, and the best steam coals are inferior coking coals, while both contain a large percentage of hydrogen.

Desulphurization.—The production of coke is undertaken with the same general object in view, as the production of wood charcoal; but it is desirable, for many purposes, to free the coal from sulphur. In this sense the production of coke may also be called the desulphurization. For purposes connected with the arts coke must be compact, in large pieces not liable to crumble and form dust, and it must possess a certain degree of solidity so as to withstand the pressure in smelting furnaces. Both qualities must be considered in the choice of the material selected for its production.

Experience has proved that the softness of coke is very much dependant upon the mode of its production, and that it may be rendered more compact by management in the ovens. If, for instance, coke is prepared under considerable superincumbent pressure the blisters which form in the softened coal are pressed together, after the escape of the gases which caused them, and a denser coke is produced, while the long-continued heat of some ovens tends to render the coke more dense and hard. In order to obtain good coke, caking coal, which approaches sinter coal in composition, should be selected.

In the production of coke from the small coal of the northern coal-field of England, nearly every description of caking coal will make good coke; provided the Duff be screened out, in which the whole or nearly all of the shale and mineral matter is found.

One of the most injurious mineral ingredients of coal is the common iron pyrites, the sulphur in which is not entirely removed by the operation of coking, while the oxide of iron which remains in the coke forms with the siliciate a slag or scar when the carbon is consumed. This scar, covering the grates of a locomotive furnace, for example, prevents the free access of air, wastes the fuel, which is thus to a much greater extent only converted into carbonic oxide, and diminishes the speed by arresting the rapid production of steam. Hence it has been found in practice that a coke which leaves a white ash, although containing twice as much as another yielding oxide of iron, is much superior for locomotive purposes. Fortunately, this constituent of certain cokes actually renders them more adapted for smelting some lead-ores than the others, as, for example, on the east coast of Spain where the oxide of iron acts as a precipitant for the lead in the furnaces.

As the presence of sulphur or pyrites is thus injurious where coke is employed for locomotives, or in re-melting iron for foundry purposes, it has been proposed to remove the sulphuret of iron from the coal by mechanical means. This has been adopted in Belgium, and France, and is now being carried out by Mr. Morrison in Durham. The Belgian plan is similar to that employed for washing lead and zinc-ores, &c., and has been for some time in operation in the Vosges where the coal is much impregnated with pyrites. M. Lechatélier in his Report to the Minister of Public Works in 1848, overlooking the facts we have just mentioned, adopts the following empirical rules in estimating the value of coke.

When the ash does not exceed :

6	per cent	the coke is good.
6 to 9	„	the coke may be used.
9 to 12	„	the coke is bad.
above		the coke is worthless.

The plans adopted for washing coal are detailed in the accompanying drawings.

FIG. 33.

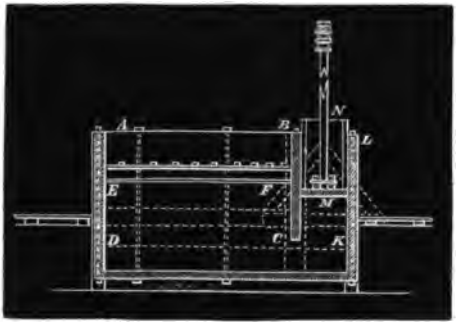


FIG. 34.

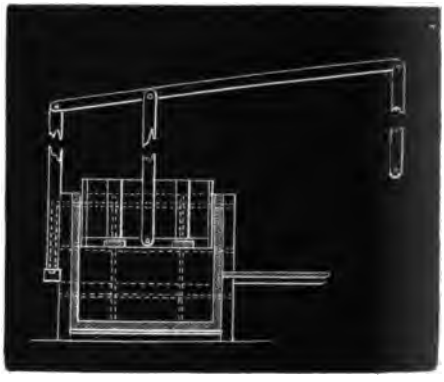


FIG. 35.

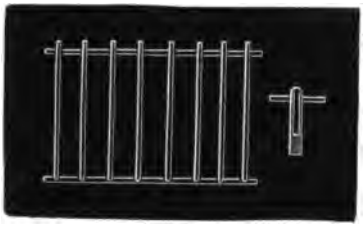
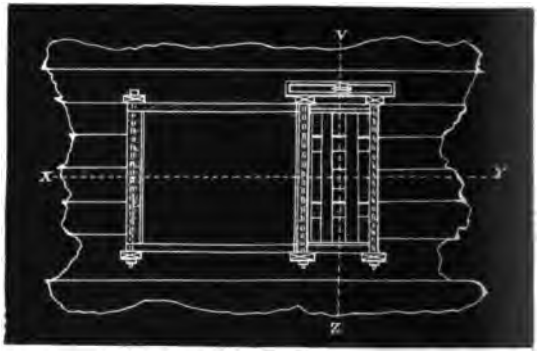


FIG. 36.



Figs. 33, 34, 35, 36 designs of a piston cylinder for washing the coal.

A B C D, compartments for the grate.

E F, grate on which the coal rests.

G H, bars below which the shale accumulates.

B K C L, compartments for the piston *M N*.

FIG. 37.

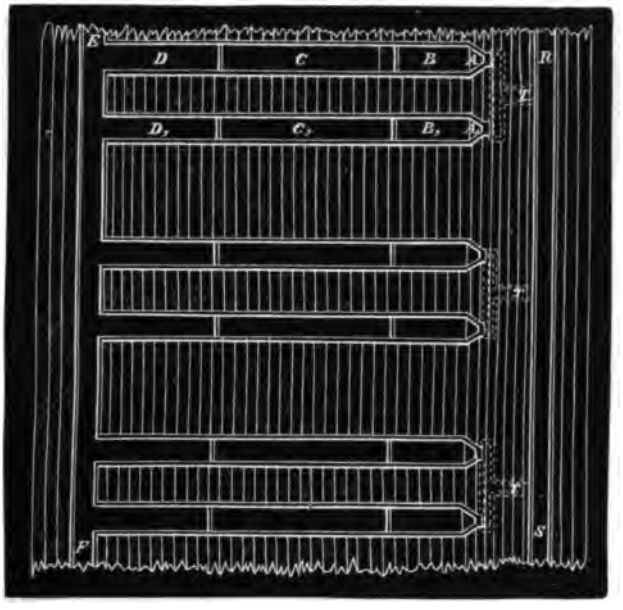


FIG. 38.

Figs. 37 and 38, plan and section of the process employed at Commentry.

R S, channel for conveying the water to the washing place.

T, channel intended for the washers *A B C D* and *A, B, C, D,*.

A A, sluices for regulating the admission of the water.

B C D B, C, D, three distinct compartments for washing.

E F, exit for the water.

FIG. 39.

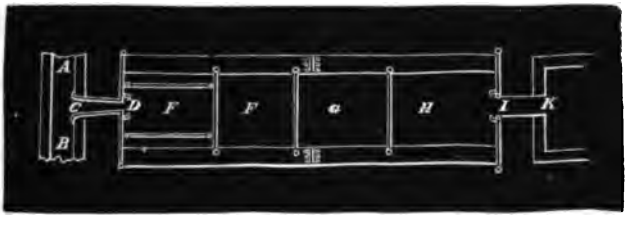


FIG. 40.

Figs. 39 and 40, plan and section of the washers at Felessin.
A B, general canal for conveying the water to the apparatus.
C, regulating sluices.
C D, canal for admitting the water.
E, first compartment, where the stones are deposited.
F G H, other compartments.
I, the point where the steel division is placed to retain the coal.
K, exit for the water.

The general results are said to be that three workmen, during the twelve hours, can wash 11 to 15 chaldrons, and the produce is in 100 parts :

Washed coals	89
Shale . . .	2
Small coal .	9
	100

while the quanity of ash in the coal has been reduced nearly one half. The small coal contains 20 to 25 per cent of ash. The cost may be calculated from the French data, as follows:

	d.
Labour . .	5.1
Other charges	1.2
Loss . . .	8.3
	14.6

or about 1*s*. 2*d*. per ton of washed coals, which on a produce of 66 per cent of coke, would make the cost 1*s*. 10*d*. per ton of coke.

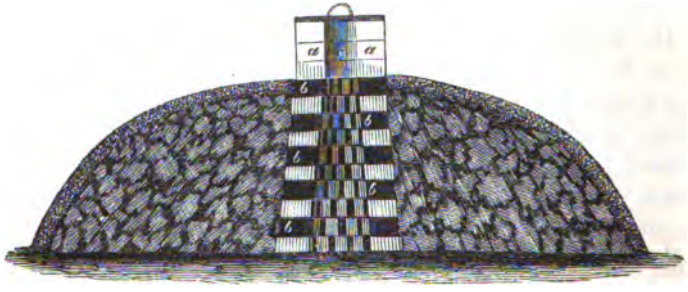
Coke being much less inflammable than charcoal, only burns well with a good draught, and is soon extinguished in kilns with little draught and in the open air, and the coal from which it is produced being always furnished on the same spot, fewer precautionary measures are requisite in preparing it, and the operation of coking may be easily and most economically carried on in a fixed plant.

Coking in Heaps or Ridges.—The oldest and still very common method of preparing coke is in meiler or heaps, in which, however, the operation is not conducted in the same manner as in the wood meiler. No covering is employed, but carbonization is permitted to commence with free access of air, a coating of dust being first applied when the coke has already been produced, and the attention of the burner is required to prevent its further consumption. The foundation for the meiler being stationary, it becomes sufficiently covered of itself with coke debris. In order to prepare larger quantities of coke at once, long ridges are often substituted for the original round meiler, the length of which varies with circumstances and the consumption of coke; they may sometimes extend to the length of 200 feet. On erecting one of these ridges, a string is stretched along the coking station, in the direction of which large pieces of coal are placed slanting against each other, leaving a triangular space between them, so that a longitudinal channel (ignition passage) is formed, through which the string passes. In arranging the pieces, it is necessary to pay attention to the natural stratification of the coals, which should be at right angles to the longitudinal direction of the ridge. Parallel with the first series of coal, is placed a second, and then a third, and so on; but the pieces constantly diminish in size, until the station measures six feet on both sides. Upon this substructure the heap is then made, without particular care in the arrangement, the largest pieces below and the smallest above, until it has reached a height of about two feet. To facilitate the ignition, stakes are rammed in at distances of two feet from each other, projecting above throughout the whole length of the ridge, which when subsequently removed, leave vacant spaces for the introduction of burning coal. The ridge being thus kindled at more than a hundred distinct spots, soon breaks out into active combustion.

As soon as the burner observes the thick smoke and flame cease at any one part, and a coating of ash making its appearance, he endeavours immediately to stop the progress of the fire by covering it with powdered coal-dust, repeating the operation until the whole ridge is covered, when it is left two or three days to cool. The covering on the side exposed to the wind should be the thicker, and increased in stormy weather. When the fire is nearly extinguished, which occurs in two or three days, the coke is drawn. This mode of coking is simple, but not very economical. The fire proceeding from the upper part of the ridge in a down-

ward direction towards the lower and interior parts, converts the coal in the upper strata into coke before that in the interior has acquired the temperature necessary for charring, and is still in want of a supply of air, which can only be furnished from without, and must not be excluded by a covering. During the time, therefore, that the inner parts of the heap are being converted into coke, the outer portions are being uselessly although unavoidably consumed. A somewhat different method is carried out at the Clyde Iron Works, in Scotland, and in other places, which completely obviates this difficulty. Fig. 41 represents a section of

FIG. 41.



one of these heaps, which are constructed and managed much upon the same principles as the charcoal meiler.

A conical brick chimney, 3 or 4 feet high, is erected upon the coke station, 3 feet wide at the base and tapering towards the summit, apertures *b b b* being left between the bricks connecting the flue or chimney with the heap of coal surrounding it. The heaviest pieces of coal are placed nearest the chimney, the smaller pieces towards the outside, by which arrangement the heap assumes a rounded shape. The inclination of the heap must be such, that the covering of small coal or cinders with which it is enclosed may have sufficient support. The chimney is either covered with a lid, as shown in Fig. 41, or is left open as in Fig. 42, according to the method of charring employed. In both cases, however, six or eight open channels in connection with the interior of the chimney are made at the foot of the heap, to admit air, which is more requisite to keep up the combustion in coal than was the case with wood. The ignition is effected by the chimney, into which burning coals are thrown, which gradually communicate the flames to the heap through the apertures *b b*. Combustion thus commences in the centre, and extends towards the circumference in a direction

opposed to that of the air. The flame and smoke escape through the open chimney. The coking is finished as soon as these cease to be evolved, and the mouth of the chimney is closed with an iron door, as are also the holes at the foot of the heap, and any that may have been formed in the covering with small coal and dust.

A heap of 20 feet in diameter and 3½ feet high, may be charred in this manner in about two to two and a half days, while the same time is required for the coke to cool.

FIG. 42.

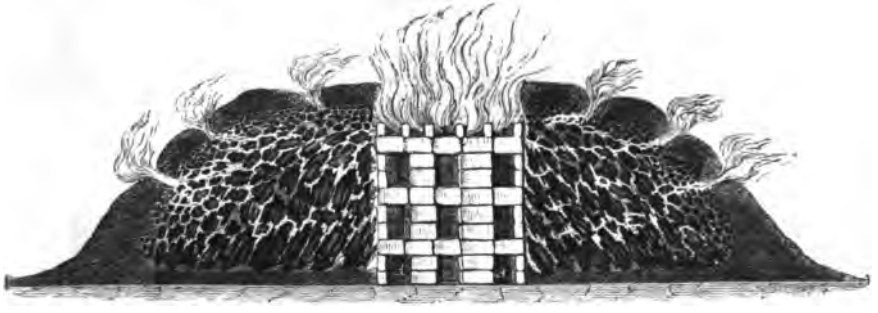


Fig. 42 represents one of these heaps in the process of coking. It is constructed, however, in a somewhat different manner, being higher than the chimney, and the flame being allowed to find its way through the covering in different parts. In other places, where similar heaps are erected, the process is conducted in a different manner, and resembles that practised with the ridges first described. No covering is then used, and the chimney is closed with an iron slab immediately after ignition. The flame then penetrates the meiler, fed by the air which everywhere has free access; as soon as it disappears at any spot, the part is protected with cinders or small coal, and so on until the whole meiler is covered. The heat is now sufficient to drive off the last portions of vapour and tar, which pass out through the chimney. When these cease to be evolved, it is again closed and the meiler allowed to cool.

Coking in Ovens.—In many countries coke is more economically made in ovens. The ovens intended for the production of coke alone (and not of tar and gas, for which see Gas Illumi-

nation), depend upon the partial access of air, and are not worked by means of external heat. A series of coke-ovens, as they were formerly constructed at the Tyne Iron-works and elsewhere, are shown in Fig. 43, and in horizontal section at

FIG. 43.

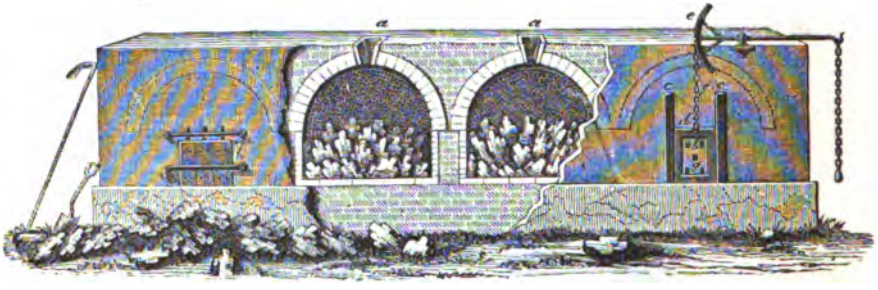


FIG. 44.

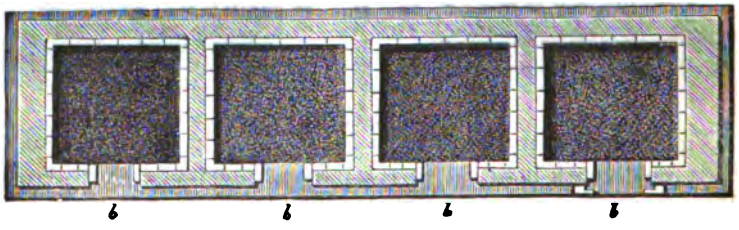


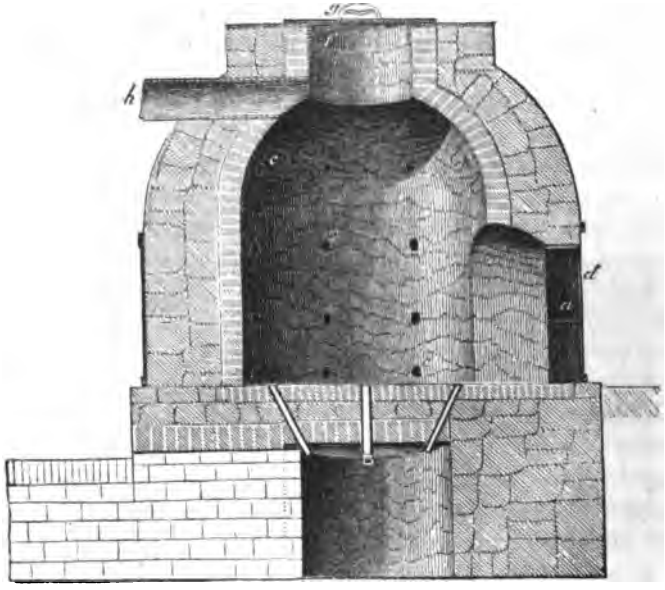
Fig. 44. The drawings represent four ovens, ranged together in order to save brickwork and retain the heat; a better plan, however, is shown in Fig. 58. Each separate oven is a square space, constructed of brick, and arched over at the top, 10 feet deep by 12 feet wide, affording space for a mass of coal 120 feet square by 10 feet high. The whole thickness of the wall is 2 feet, including the internal lining of fire stone. No grate is requisite, but in the centre of the arch *a*, an aperture is made 2½ feet wide, and another *b b* at the bottom of the front wall, for the introduction of the coal, and which can be closed by a door 3 feet square. The aperture *a* is supplied with an iron ring, the opening *b* with an iron casing which forms a groove *c*, in which the door slides. This door consists of an iron frame, filled with brickwork, which is moveable in *c*, by means of the lever *e* with its chain *f*, to which it is suspended at *d*. A number of holes *g g*, are either

left in the brickwork of the door for the admission of air, or the bricks of which it is constructed are loosely put together. The first oven shown in the drawing has a door of a less convenient construction.

The ovens are charged with coal, sometimes through the opening in the roof, and sometimes from the front. The former plan of loading an oven is said to produce coke of less uniform quality than the latter. The reason probably is, that being gradually charged from the front by a workman, the coal is not so dense in the centre as when falling in a mass from above, and hence more uniformly burnt. The front door is now partially closed by fire-brick tiles, which are made tight with loam or clay up to the level of the coke. If the oven is sufficiently hot, the coal ignites at the edges where it is in contact with the heated brick surface; but the workman sometimes assists the ignition by throwing in a small quantity of sulphur. As long as dense volumes of smoke or flame are evolved, the air is allowed free ingress through the openings in the upper tiles; but when all flame disappears, both apertures are made perfectly close, and the oven is allowed to cool down for various periods from twelve hours and upwards. The coke is then withdrawn by rakes, and the whole cooled down by water. The quantity of coke which one oven will hold varies from 3 to 9 or 10 tons, and the period of coking from forty-eight hours to six or seven days.

In most coal countries, large quantities of tar are obtained in the production of coal-gas for illumination, but the secondary products of the coking process are not collected. In Silesia, on the contrary, the industrial relations of the country are so distinctly in favour of collecting the tar, that the ovens are always constructed with that view. In Gleiwitz, for example, the form of oven or kiln represented in Fig. 45, has been employed for some years, which plan, in a somewhat different form, is in use in this country—the ovens being constructed of iron, and lined with brick. These kilns are about 8 feet high, of a cylindrical form, and constructed of brick. They are charged by the opening *a*, which is afterwards bricked up, and enclosed by an iron door *d*, the crevices in which are filled with clay; *f* is the mouth of the furnace, with an appropriate cast-iron door *g*. The air has access by the apertures *c c c*, which are ranged one above the other in rows, reaching to the arch. The lowest of these are in the sole of the kiln itself, which, being supported

FIG. 45.

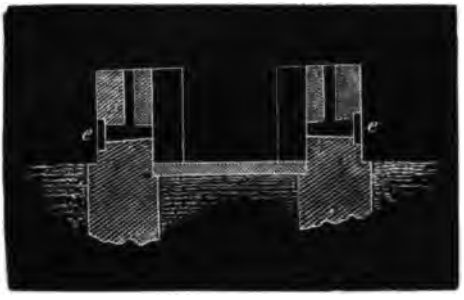


at the sides, thus becomes a kind of grate. It is better, to make the sole of massive brickwork, so that the draught-holes may proceed from the sides. The tar vapours and gases are conducted during the operation, through the tube *h* in the side of the arch to a cistern, which condenses and collects the former, allowing the latter to escape. During the cold season the tube *h* leads directly to this cistern; but in summer it is carried in a zig-zag manner through a water-tank, for the purpose of aiding the condensation.

In charging the kiln, large lumps of coal are introduced at *a*, leaving a space for the insertion of burning coals, then smaller pieces at *f*, in all about 35 to 40 cwts. When the first portions have taken fire, the two larger apertures, and the upper rows of draught-holes *c c* are closed, the lower row only being left open. As soon as the fire, as seen through these openings, assumes a reddish-yellow colour, they are closed, and the second row opened, and so on. The first row is closed after ten hours, the second is allowed to remain open for the same time, the third row sixteen hours, and the last, or uppermost, three hours, after which, the oven is left for twelve hours before the coke is drawn. With four of these ovens, eight or nine cokings are made weekly at Gleiwitz.

The coal which is used there is of a slightly caking character, without being very deficient in hydrogen. One hundred parts of coal produce, on an average of several months' trials, 74 parts by volume, 53 per cent by weight of coke, and about 5¼ gallons of tar. The same coal, charred in the heaps, produces only 47 per cent by weight of coke, which is much more porous and less dense than oven-coke, an equal bulk of the latter weighing nearly ⅛ more.

FIG. 46.



A process for coking small coal in open ovens has been very successfully carried out at the same place, the construction of the ovens being shown in Figs. 46, 47, 48. The coal is wheeled into the ovens through the openings *C* and *D*, Fig. 48,

FIG. 47.

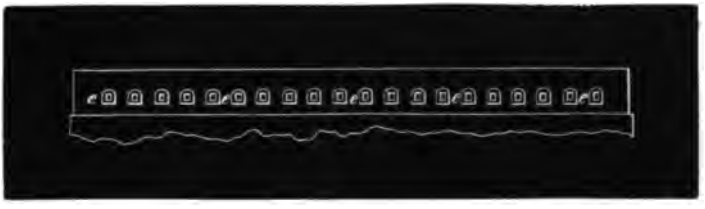
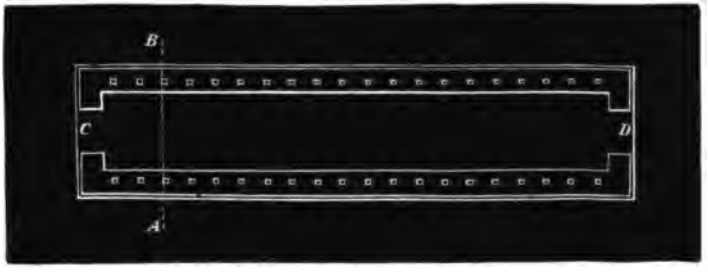


FIG. 48.



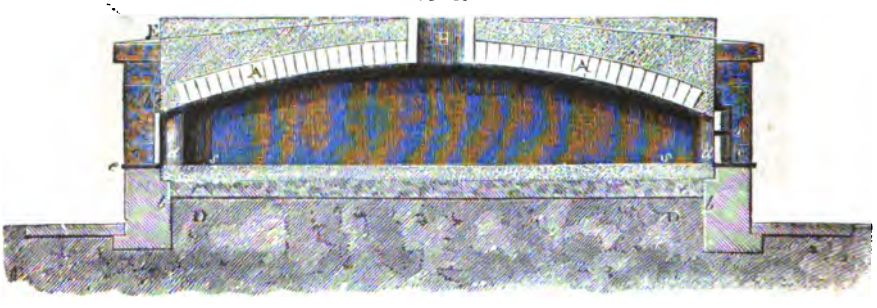
moistened with water, and well beaten down; while pieces of wood, 4 to 6 inches thick, are laid on the coal, stretching across the whole width of the ovens. These pieces of wood correspond

with the openings or air-channels *e e e*. The oven is filled to the level of the outer wall in this manner, covered with clay and coal-ashes, well beaten down; and fire being set to the wood, the process is conducted with much the same precautions as in the manufacture of charcoal in heaps.

The ovens are 8 feet wide, 5 feet high, and 44 to 60 feet long, holding 200 to 300 tons, and the operation lasts from ten to twelve days. When carefully managed, the loss does not exceed 20 per cent.

The refuse coal from the pits, coal-dust, &c., which, in itself, is of very little value, can often be converted into coke, particularly if it is of a caking nature, as the small pieces become soft with the heat, adhere together, and form solid masses of coke. At St. Etienne, an attempt was made to stamp moist coal-dust into wooden boxes constructed in the form of a small heap or meiler, which could easily be taken to pieces, and were furnished with pegs on the inside, with corresponding draught-channels. These were ignited after the removal of the mould; but they involved too much manual labour and a very considerable loss, and have been supplanted by the use of closed ovens, one of which is represented

FIG. 49.



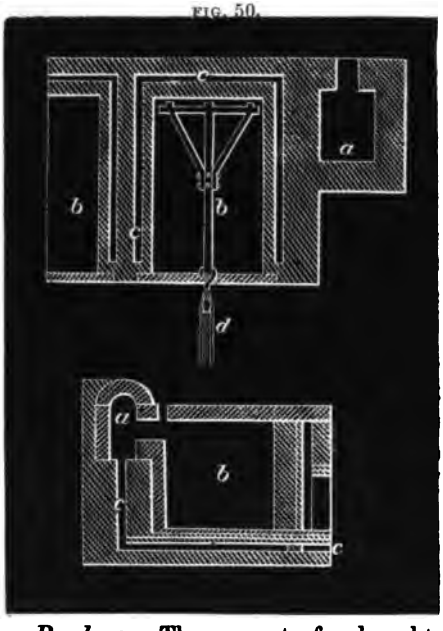
at Fig. 49, being the form employed at Rive de Gier, on the Loire. The construction is the same in principle as the common baking-oven; a slightly-arched space with a flat sole, without grate, which, heated by the previous operation, ignites the charge. The bed of the oven *s s* is oval-shaped, 11½ feet wide by 23 feet long, composed of a mass of clay 6 inches in thickness, which is spread out and stamped upon a layer of small stones, *t t*, through the interstices of which its moisture can escape. The space *D D* below the bed of the oven is filled with earth or rubbish. The working holes *d d* opposite each other, 2.8 feet wide, and 2 feet high, are placed

in the lowest part of the arch, each of which is surrounded by a framework of cast-iron fixed in the wall, in which the sliding-door *P* moves up or down. The door is a flat iron box, lined with brick-work, to resist the heat. There is a small aperture *o* in the middle of the door through which the workman can observe the progress of the operation. The arch rises 4 feet above the bed of the oven in the centre, its highest point, where a small chimney *H* is introduced, 1.6 feet in diameter, and 1.8 high. The interior of the oven, at *H* and *A*, is constructed of fire-bricks and clay; common stones, covered with a layer of mortar mixed with sand, form the exterior.

As soon as the coke from a previous operation has been removed, the oven is again charged with coal-dust, previously moistened, that it may easily cake together and yield a better produce of coke. The depth of charge should not exceed 8 inches with strongly-caking coal, or 10 when it is less caking: it should be spread out uniformly, and the doors closed, with the exception of a narrow slit at the bottom for the introduction of air. The oven will hold from 60 to 70 cubic feet of coal. When the heat begins to act upon the coal, aqueous vapour, sulphurous and combustible gases are evolved; and it is found expedient to prolong this stage of the process as much as possible, in order to secure a large produce of coke. This part of the operation should occupy two hours, the slight draught being only just sufficient to carry off the vapours; the evolution of aqueous vapour soon ceases, and the combustible gases passing off in greater quantity suddenly ignite with a kind of explosion, the yellow smoke ceases for a moment, and is succeeded by a black cloud. At this stage of the process the mass of coal is at a low cherry-red heat, and it becomes necessary to increase the draught in order to drive off the whole of the vapours and volatile matter. The door is therefore raised about 3 inches, when the fire immediately draws up, and a dusky, sooty flame issues from the chimney. After three quarters of an hour this becomes clear and white, the heat is then uniformly spread over the whole mass of coal, which begins to split and crack, and must not be disturbed. In three quarters of an hour after these fissures have extended to the very sole of the oven, and when the whole is at a full red heat, the door is closed, and all crevices filled with clay. The heat now generated is sufficient to complete the carbonization and to drive off the last portions of volatile matter. For a time the flame still

flickers, becoming whiter and whiter, at a considerable distance above the chimney, but gradually diminishes, threatening to die away altogether, the evolution of gas from the interior having entirely ceased. If more time were allowed, the air would, at last, enter by the chimney as the pressure diminished, the cover is consequently advanced, until it is completely closed. The coke is now removed as quickly as possible to avoid any loss of heat, and the doors being suddenly opened, the mass of coke is broken up with staves, raked into barrows, sprinkled with water, partly to quench the fire more rapidly, and partly to decompose the remaining sulphur compounds, the presence of which are recognised by the odour of sulphuretted-hydrogen arising from the glowing coke. Another charge is then thrown into the oven, and the same process repeated, the operations occupying about twenty-four hours.

FIG. 50.



In Belgium, a series of coke-ovens, of the construction shown in Fig. 50, are employed, *b b* being the body of the oven, *a* the chimney-flue, *c c c* a cold-air flue in connection with the chimney; *d* represents an apparatus for drawing the whole charge of coke at once.

Produce.—The amount of coke obtained from coal varies with the temperature employed in the manufacture; but according to Karsten's experiments, the variation is not so great as was observed with charcoal. With wood, nearly double the quantity of charcoal, or 12 per cent more, was obtained by charring at a low heat; with coal, there is only a gain of 5 or 6 per cent in coke. More depends here upon the quantity of carbon in the coal, the amount of ash that it yields, and the manner in which the elements, carbon, hydrogen, and oxygen, are combined. In consequence of these numerous conditions upon which the yield of coke depends, it is

extremely difficult, if not impossible, to predict what will be the amount of produce from any given specimen without a direct experiment. The importance of this determination of the amount of coke yielded by any specimen of coal, for its application as fuel in the arts, is so great that vast numbers have been analyzed, some of the results of which examination have already been given in the tables at pages 51—54. We here add a further table, and refer to those at the end of the volume.

The quantity of coke obtained from British coals, as examined by the authors of the Admiralty Report, &c., (*vide* p. 53) averages from 54.22 to 72.60 per cent.

The produce of the American bituminous coals, examined by W. R. Johnson, was from 53 to 76.6 per cent. as will be seen in one of the columns of a table below (*vide* Relative Value of Fuel).

The following are the quantities obtained by Karsten from Continental coal, of various districts, distributed according to the usual foreign classification:

100 parts of Coal from:		Yield: coke.	ash.	pure carbon.
	SAND-COAL.			
Upper Silesia	Caroline	65.6	2.8	62.8
	Charlotte	67.5	2.42	65.08
	Beate	66.8	11.9	54.9
	Theodor	53.5	1.9	51.6
	Josepha	56.9	3.4	53.5
Lower Silesia	Laura	70	1.85	68.15
	Laura	73.5	2.4	71.1
	Fuchsgrube	59.1	2.1	57
Saarbrücken	Geislautern	62.1	3.9	58.2
England	Cannel-coal	69.8	13.3	56.5
	Brazils	59.5	1.6	57.9
	Ditto	66.5	28.4	38.1
	SINTER-COAL.			
Upper Silesia	Königin Louise	67	1.2	65
	Königsgrube	65.3	0.6	64.7
	Henriette	63.8	1.65	62.15
	Treue Caroline	61.5	4.8	56.7
Lower Silesia	David	68	2	66
	Louise Auguste	66.5	1.3	65.2
	Frischauf	78.8	23.4	55.4
	Ditto	73	8	65
Saarbrücken	Prinz Wilhelm	62.1	1.3	68
	Merchweiler	61.88	0.9	60.98
	Gerhardgrube	58.5	1.6	56.9
Saxony	Planitz (Pechkohle)	64.5	1.1	63.4

100 parts of Coal from:		Yield: coke.	ash.	pure carbon.
	CAKING-COAL.			
Upper Silesia	Friedrich zu Zawada	60	2.1	57.9
	Sackgrube zu Ezernitz	58.5	5.8	52.7
	Stollenflötz zu Hultschin	86.9	2.1	84.8
Lower Silesia	Gnade Gottesgrube	66.8	4.65	62.15
	Gustavgrube	69.9	1.9	68
	Glückhilfgrube	68	0.8	67.2
	Kombinirte Abendröthe	75	4.9	70.1
Saarbrücken	Sulzbach Duttweiler	64	0.15	63.85
	Friedrichsthal	64.8	0.65	64.15
	Wellesweiler	65.6	1	64.6
Saalkreis	Wettin	78	10.8	67.2
	Ditto	81.1	24.4	56.7
	Ditto	77.5	5·1	72.4
Eschweiler	Fornagelflötz	80	1·3	78.7
	Schlemmerichflötz	84.5	3·25	81.25
	Flötz-Gyr	81.5	1·17	80 33
Westphalia	Hütterbank	86.3	1	85.3
	Sälzer und Neuack	82.3	0.7	81.6
	Stock und Scheerenberg	80.1	0.65	79.45
England	Cannel-coal	51	0.5	50.5
	Ditto	61.5	5.5	56
	Newcastle	68.5	0.85	67.65
Saxony	Pottschappel (Gute Schicht)	68.7	27.7	41
France	Burg-Lastic	82.9	5.8	77.1
	Anzin	75	3.5	71.5
	Foudary	78.8	7.2	71.5
	Creuzot	68.8	3.4	65.4
	ANTHRACITE SINTER-COAL.			
Upper Silesia	Therese zu Hultschin	88.4	2.66	85.74
Saalkreis	Löbejün	89.1	9.1	80
	Ditto	90	20	70
Westphalia	Turteltaube	86.8	2.4	84.4
	Louisen-Erbstollen	72.8	1.4	71.4
	Sperling	85.5	3.5	82
	Hamburg	89.1	0.9	88.2
Belgium	Mons	88	2.5	85.5
	ANTHRACITE SAND-COAL.			
Principality of Badenberg.	Neu Langenberg	93.6	0.8	92.8
	Hoheneich	94.8	1.2	93.6
	Fürth	95	0.7	94.3
	Abgunst	96.4	1.75	94.65
Saalkreis	Löbejün	92	7	85
	Ditto	90	9.9	80.1
Westphalia	Alter Hase	92.5	1.7	90.8
	Hundsnocken	92.8	0.6	92.2
	Schwarzer Junge	91.9	1.1	90.8

If the percentage of coke obtained from the pure organic portion of the coal (*i. e.*, the ash deducted) be calculated from the tables above, and compared with the actual quantity of carbon

contained in the coal as deduced from former tables, we shall find the following relations:

	Actual carbon contained in coal per cent.	Coke produceable from coal per cent.
Sand-coal	75—80	55—65
Sinter-coal . . .	80—85	60—70
Caking coal	85—90	60—80
Anthracite sinter-coal Anthracite sand-coal	90—95	85—94

It has been shown, however, by Regnault, that the percentage of carbon in the coal is not always a correct indication of the quantity of coke that it will yield, and that greater differences in coke produce, even than those stated above, occur in some varieties of coal, so that both by theory and experiment it is proved that no certain amount of coke produce can be obtained from a coal of a known percentage of carbon; and that the only safe criterion on which every large consumer of coke can base his calculations, must be the mean actually obtained from a large number of coking operations.

The annual average, from observations made at Rive de Gier, was 69 per cent coke; with inferior coal and less care, not less than 60 to 65 per cent were obtained; whilst coal and pit-dust in the heap, only yield 45 to 50 per cent; and in the ridges, rich coal yields 40 to 45 per cent. Coal containing little hydrogen produces $\frac{1}{8}$ more. General experience has shown that the oven produces denser coke than the heap; and this, again, coke more dense than the ridges; and yet the coals in the two latter cases scarcely yield their own volume, whilst in the ovens this increases in the ratio of 10:12. On the other hand, the smelters find the coke from heaps and ridges much more free from sulphur than that made in ovens.

Nature of the Coke.—The physical appearance, as also the chemical constitution of coke, varies with the nature of the coal from which it has been prepared and with the mode of its preparation. It is generally a highly porous vesicular mass, varying in colour from a blackish-grey, with a more or less fatty lustre, in that prepared from coal rich in oxygen, to a light iron-grey, with a fine silky or almost metallic lustre, in that obtained from caking-coal, which has much resemblance in structure with a mass of melted slag or lava. A play of colours is often observed in some

varieties of coke, and is said to be indicative of the presence of sulphur. Good coke should be uniform throughout, without any great admixture of fibre coal or shaly matters; it should be dense and compact. Coke, like charcoal, attracts moisture from the air, often as much as 30 per cent, and it is said to possess greater heating power after having been kept for some time, the cause of which is as inexplicable as in the case of charcoal. Too much exposure to the weather renders it soft and liable to crumble. The amount of ash depends of course upon the amount contained in the coal, and is greater in proportion to the lesser quantity of coke obtained.

The following selection of analyses will give some idea of the composition of the different cokes used in this country:

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Carbon	95.51	86.86	90.53	94.21	93.41	93.05	89.87	84.83	96.43	97.60
Ashes	2.85	12.07	8.46	5.10	5.80	5.37	8.35	14.40	2.75	1.55
Sulphur . . .	1.64	2.08	1.01	0.69	0.79	1.58	1.78	0.78	0.83	0.85
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	11.	12.	13.	14.	15.	16.	17.	18.	19.
Carbon	94.08	93.44	89.69	91.16	93.54	91.49	94.31	94.67	93.70
Ashes	5.04	6.00	8.35	7.65	5.70	7.05	4·97	4.96	5.70
Sulphur . . .	0.88	1.56	1.96	1.19	0.76	1.46	0.72	1.07	1.60
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In smelting operations, it is of great importance that the coke should be *hard* burnt, so as to be dense and capable of resisting the action of the blast. Coke of this quality carries twice the burden of ore, and produces—in iron-smelting, for example—a metal of a very superior quality. The nature of the ash is, however, of less importance in smelting than in the locomotive, where the quantity is not so serious an objection, provided it does not scar, so as to obstruct the draught; hence some cokes, which contain a large percentage of white ash, as No. 2, are preferred to those which melt on the grates, though much smaller in quantity.

Great importance is attached to the bright, silvery metallic appearance of the coke; and some experiments were made three or four years ago to improve this property, by dissolving common salt in the water with which the coal was moistened, but without effect. The use of salt in removing sulphur in coke has since been patented by Mr. Calvert, and its action in the coke-oven is explained by him as follows: The bisulphuret of iron contained in coal is first converted by the heat of the oven into sulphur and protosulphuret of iron. The latter, when salt has been added, coming into contact

with the vapour of the salt, is converted into protochloride of iron, sulphuret of sodium being simultaneously formed. The protochloride is then said to be decomposed into subperchloride with the evolution of chlorine, which, acting on the sulphuret of sodium, produces again chloride of sodium and chloride of sulphur; which latter is disengaged, leaving a much less quantity of sulphur in the residual coke, and that being in the harmless form of sulphuret of sodium.

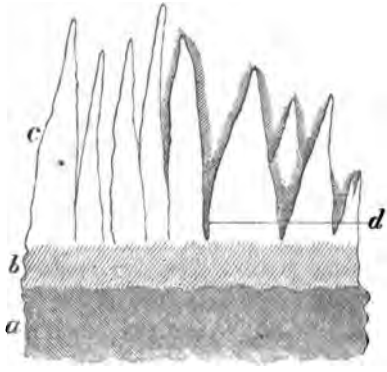
Coke thus prepared is said to yield very superior iron in the cupola.

The preparation of coke has become a very extensive trade in this country within the last few years, in consequence of the increasing demand for railways and smelting operations; and the small coal, which was formerly of comparatively little value, has, in consequence of its peculiar adaptation to the production of coke, become a most important source of profit.* So superior indeed is the coke made from small coal, both in density and strength, that it has even been proposed, in some cases, to grind the large coal for the purpose of making coke. There is some difference as respects the management of different qualities of coal in converting them into coke. The great object of the coke-burner is to produce a dense, compact coke, in such large masses, that in cases of long carriage, either by sea or land, these lumps may arrive at their destination without being broken up into such small pieces as to be unfit for smelting or locomotive purposes. This object is most effectually accomplished by burning large quantities of coal of sufficient depth to ensure long upright masses of coke in the oven at the end of the operation. But some coals, which contain a large percentage of ash, form a coke which melts easily, and when the ovens are charged with too deep a load of such coal, the coke melts, and covers the upper layers in such a manner that the air cannot penetrate to the unburnt coal at the bottom of the oven, and the produce is a mixture of charred coal and coke. On the other hand, when coal contains a large proportion of ash, which does not melt in coking, the same result is observed. This arises, however, from a different cause, the mass of coke at the top which is first formed continues to burn, leaving its ash on the surface, and this accumulating, at length falls down into the crevices, and chokes the fire before it has time to reach the bottom

* One company near Newcastle-on-Tyne producing upwards of 200,000 tons per annum.

layer of coal; thus, in Fig. 51, *a* is the unburnt coal, *b* that partially coked, *c* the coke already formed, and *d* the ashes which have fallen down, and prevented the access of air to support the combustion. In such cases, the difficulty in the coking process is obviated by building smaller ovens, and loading them lightly.

FIG. 51.

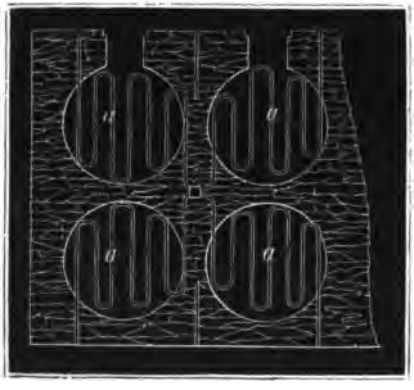


When suitable coal exists, the advantages of heavy loading are very obvious. The whole mass of coke is longer exposed to the hardening effect of the fire, and the heavy products of distillation, ascending from the bottom layers of coal, deposit large portions of their carbon on the side of the already formed coke, thus increasing the produce from a given quantity of coal. The ovens about to be described are now generally constructed to contain from 7 to 10 tons of coal, and produce a most superior coke, both as respects quality and quantity.

After the oven has ceased to burn, the whole is made perfectly close, and the coke kept in the heated state for some time, contracts in bulk, and becomes much harder and more compact. In coke intended for iron and other smelting operations, where it is exposed to the action of a blast, long before it really does any efficient duty, the above qualities are most valuable.

Figs. 52, 53 and 54, are drawings of the ovens, showing them in different positions, about 10 feet in diameter, and 4 feet from the floor to the springing of the dome; and in favourable localities each oven will cost about £25: *a*, Fig. 52, indicates a series of flues under the floor of the ovens, ending in a chimney *b*, the object of which is to assist in cooling the floor as rapidly as possible after the coke has

FIG. 52.



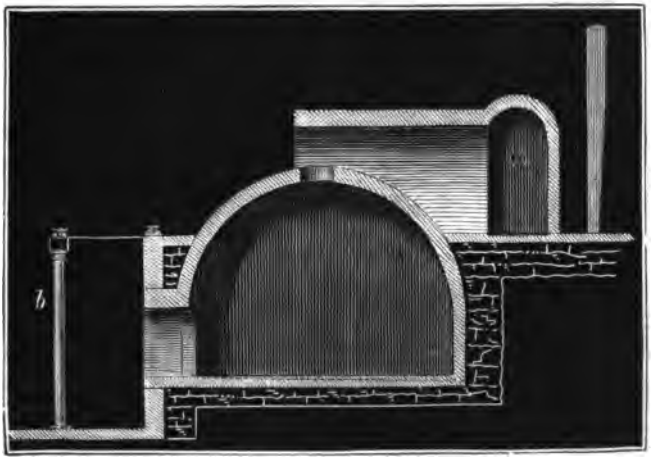
been drawn out, so that there may be no distillation of the coal of the next charge, which would tend to produce an inferior coke at the bottom. It may also be noticed here, that the dome ought to be made as flat as possible consistent with durability, in order to reflect the heat as much as possible down upon the coal, and preserve the heat of the oven generally.

FIG. 53.

FIG. 54.

Figs. 55, 56, and 57, show a similar form of oven, in which the smoke is, however, carried along the flues *a* to a high chimney, thus avoiding the inconvenience of the large volumes of smoke which are poured forth by a range of coke ovens; *b*, Fig. 55, is a cast-iron pillar sup-

FIG. 55.



porting a railway for conveying the coal waggons to any particular oven, so as to be charged in front, it having been found that when the coal is more equally spread in the ovens by manual labour, the charge is burnt off in less time than when the waggon discharges the coal into the oven all at once through the opening in the dome, independent of saving in the wear and tear of the dome occasioned by the passage of heavy coal waggons.

Fig. 58 represents the arrangement now generally adopted

FIG. 56.

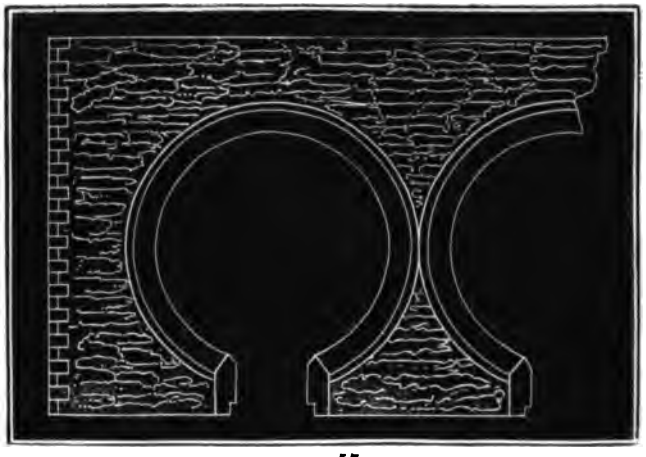


FIG. 57.

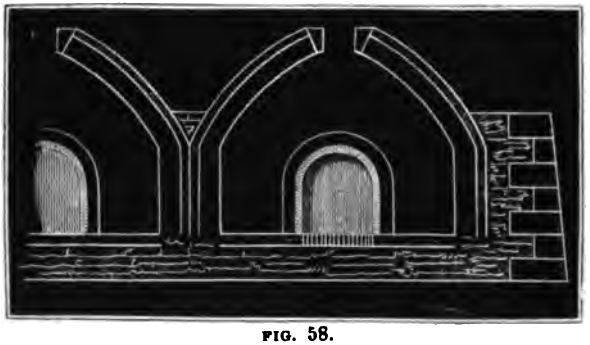
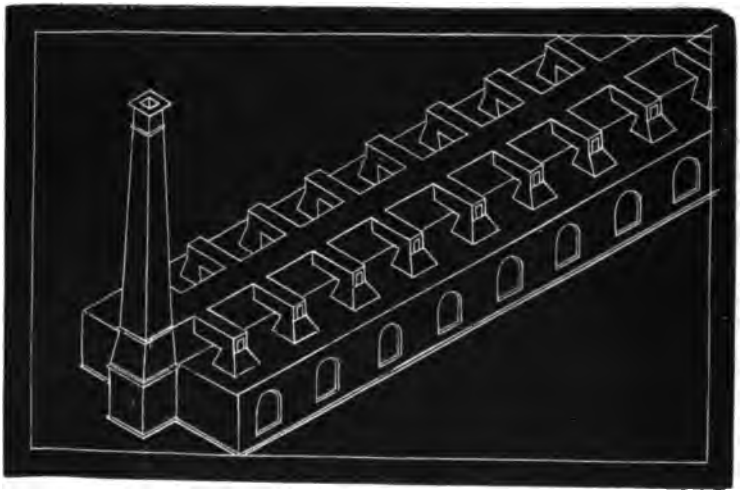


FIG. 58.



where there are a number of coke-ovens, both for the purpose of economy in the construction and to carry off the products of combustion by one chimney.

A patent has been secured for drawing the whole of the coke at once from the oven, so as to save labour and time, but it has not come into general use. Indeed, the great point to which attention ought to be directed is, especially to increase the yield and the rapidity of the coking process, so as to save the great waste from the escaping gases and small residual coke, technically called *brees*. The large ovens have in some measure remedied this latter point, and an attempt to convey the waste heat between the lining of the ovens and the outer wall to facilitate the coking operation, did not answer in an economical point of view, the first and subsequent expenses amounting to more than the gain.

M. Ebelmen has made an interesting series of experiments to determine the composition of the gas which escapes from coke-ovens. The coke-ovens of Seraing, constructed as shown in the accompanying drawings, were the subject of the experiments.

Fig. 59 shows a vertical section through the ovens, and the boiler which is set above them, and a longitudinal elevation of a part of the range.

FIG. 59.

Fig 60 is a section according to the line *A B* on Fig. 59, and a horizontal projection of the remainder.

FIG. 60.

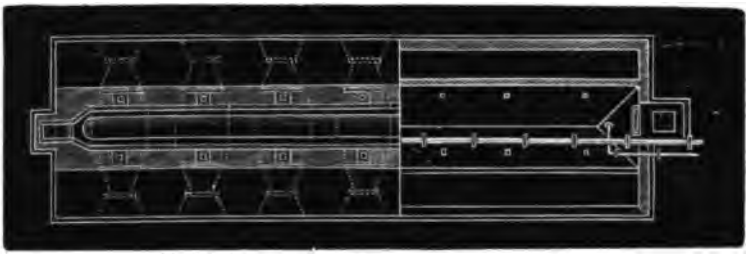


Fig. 61 shows a vertical section through the boiler.

FIG. 61.

FIG. 62.

Fig. 62, an end elevation.

Fig. 63, a section according to the line *C D* in Fig. 59.

FIG. 63.

The ovens are cylindrical, with a door at each end. There are three chimneys; one in the centre of the range, and another at each end. The dimensions of the central one is equal to those of the other two, but the three are not employed at the same time. It found that the dimensions of these chimneys is of great importance, as they regulate the admission of air into the ovens, and the rapidity of the process of coking. Eight ovens discharge their products of combustion into the central chimney, passing under a steam-boiler and raise sufficient steam for an engine of 80-horse power which drives the blast furnaces for the iron-works. The coal employed at these works belongs to the caking class, and yields by direct analysis:

Coke	Carbon . . .	78
	Ashes . . .	2
Volatile matter . . .		20
		100

The composition of the coal, approaches that of Rochebelle, which consists, according to Regnault, of:

Carbon	89.27
Hydrogen . . .	4.85
Nitrogen and oxygen	4.47
Ashes	1.41
	100.00

The coking lasts about twenty-four hours, and the yield of coke in the ovens averages 67 per cent. M. Ebelmen collected the gas at three different periods, which yielded the following analytical results:

	After 2 hours.	After 7½ hours.	After 14 hours.	Mean.
Carbonic acid . . .	10.13	9.60	13.06	10.93
Carburetted hydrogen	1.44	1.66	0.40	1.17
Hydrogen . . .	6.28	3.67	1.10	3.68
Carbonic oxide . .	4.17	3.91	2.19	3.42
Nitrogen	77.98	81.16	83.25	80.80
	100·00	100.00	100.00	100.00
Oxygen to 100 vols. of nitrogen . .	15.7	14.2	17.0	15·6

The relation, then, between the coal and escaping gas is as follows:

	Coal.		Coke, left.		Gas.
Carbon	89.27		67.00		23.68
Hydrogen	4.85				4.85
Oxygen and nitrogen .	4.47				4.47
Ashes	1.41				
	100.00	=	67.00	+	33.00

The relation of the carbon to the hydrogen is as 23.68 : 4.85, or 1 to 0.205 by weight; while the relation in the gas, according to the mean of the above analyses, is 1 to .064 by weight; from which we may infer that ⅔ of the hydrogen of the coal are consumed during the carbonization. There is a very small quantity of tar produced in consequence of the high temperature of the

ovens, which also accounts for the small quantity of carburetted hydrogen found among the permanent gases.

The mean quantity of oxygen, 15.63 for 100 of nitrogen, shows that 10.63 must have combined with hydrogen and passed off as aqueous vapour, as 26.26 parts must have been introduced for every 100 of nitrogen.

These data farther prove, that $\frac{2}{3}$ of the whole heat which is lost is sensible, and of course necessitates that it should be rendered available on the spot, as it cannot be conveyed to any great distance, and more especially as the gases do not contain much combustible matter. The heat necessary for coking is also evidently partly produced by the combustion of the products of distillation, and partly by a portion of the residual coke.

The cost of making coke in this country is about 1*s.* 2*d.* per ton.

	s.	*d.*	
Charging and burning coke, with all attendance required, including filling waggons .	0	10	per ton coke.
Filling ovens with coal	0	2	„ „ „
Wear and tear of ovens	0	2	„ „ „
Total cost	1	2	„ „ „

ARTIFICIAL OR PATENT FUEL.

It is obvious that the invention of any new or artificial fuel, is in itself an impossibility, unless the term is used to imply an adaptation of those natural fuels which have been rendered unfit for use by too great subdivision. It is in this sense that the term is here employed.

In some parts of Norway, where large quantities of saw-dust accumulate at the mills, 18 to 24 parts by bulk have been mixed with 8 parts of clay and $\frac{1}{8}$ of tar, and formed into bricks for boiler fires.

Attempts have been made to employ small-wood refuse, shavings, saw-dust, tan, charcoal- and coal-dust, and similar substances for the production of gaseous fuel, in the manner which will be described below, but they do not appear to have been attended with success. The substances chiefly employed in the manufacture of artificial fuel are charcoal-dust, peat or turf, small-coal, slack or brees, with refuse fat, tar and pitch.

Refuse charcoal, peat, and other vegetable substances, have been charred with tar and pitch, and submitted to pressure, as described at pages 93—97.

Charcoal-dust is also stated to have been economized in French iron-furnaces by allowing the blast to carry a certain portion of it into the body of the furnace.

A patent was taken several years ago, in the Austrian States, by Swozil, for converting turf into a hard substance, resembling coal, by mixing certain organic liquids with it, which gave rise to a species of putrefactive fermentation, after which it burned with remarkable ease and considerable heating power.

Mr. Hill distils dry peat, and collects the pyroligneous spirit and tar. The tar is converted into pitch, which he mixes, while hot, with peat-charcoal, and thus renders a very bulky, and, for many purposes, valueless article, one of great importance.

Weschniakoff many years ago manufactured from a mixture of small coal and refuse animal fat a substance which he called Carboleine. In this process, an excess of fat and small coal were well mixed together and made into the form of bricks, and the mixture submitted to pressure between coarse hair-cloths.

This substance, as analyzed by Kaiser, was composed of :

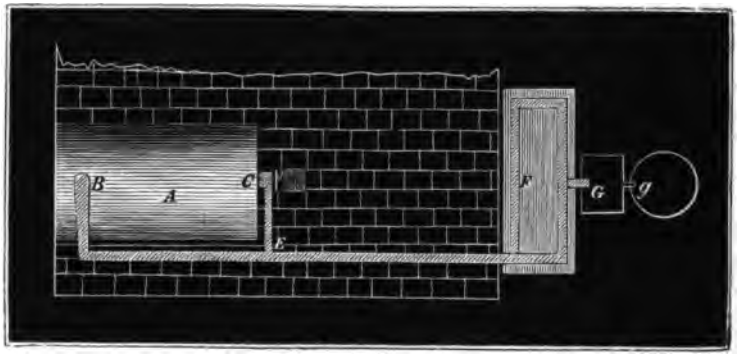
Small coal . . .	84
Fat	8
Ashes	8
	100

The specimen analyzed by Kaiser upon Berthier's plan was found to be inferior in heating-power to good English coal, owing probably to the inferiority of the coal employed in its production. Being in the form of bricks, however, it had the advantage of occupying only a small space when packed in steam-vessels, which is of considerable importance.

Another process, of a much more extensive and important nature, has been carried out into practice on a large scale by Mr. Wylam. The substances employed in the manufacture are small coal and pitch, which are moulded together by pressure into bricks. As this manufacture consists, however, of several distinct branches, it will be better to pursue them in their order. The first operation is the separation of coal-tar by distillation into naphtha, dead oil and pitch. The pitch is subsequently mixed with small coals, and then moulded. The naphtha is rectified and sold as such, while the dead oil is converted into ivory-black or employed for preserving timber. The tar is mixed with about

an equal quantity of water, which appears to facilitate the separation of the naphtha. The process of distillation is conducted by exposing the tar and water to the heat of a common fire in a large iron retort, *A*, Fig. 64. Two pipes, *B* and *C*, uniting at *E*, convey the volatile products from the retort. During the first stage of the distillation, the pipe *C* is closed by a valve at *d*, and the naphtha and water escape through the swan-neck shaped pipe *B*, which is carried about 3 feet above the retort, to prevent any dead oil passing off at the same time, during any sudden ebullition of the contents of the retort. The pipe then passes through a condenser

FIG. 64.



F, kept cool by a stream of water, and discharges the naphtha and water into the vessel *G*. The naphtha floats on the top, and flows off in a continuous stream at *g*, while the water syphons itself off by the syphon *H*, Fig. 65, as it accumulates. As soon as all the

FIG. 65.

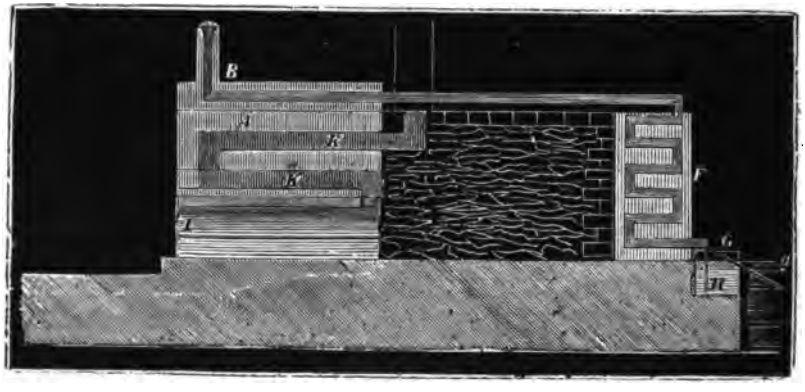
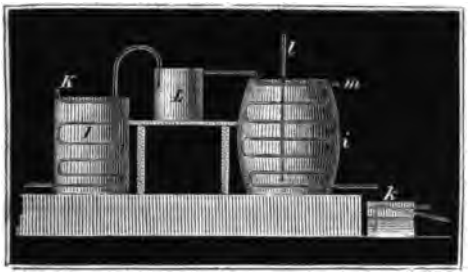


FIG. 66.

naphtha has passed over, the pipe *c* is opened, and more heat applied, until the distillation of the *dead oil* is complete. The pitch which remains behind is ultimately drawn out by an opening at the lower end of the retort, into shallow stone coolers. *I* indicates the position of the fire-places, and *K K* the flues for heating the retort. Fig. 66 shows an end-view of the swan-neck of the retort.

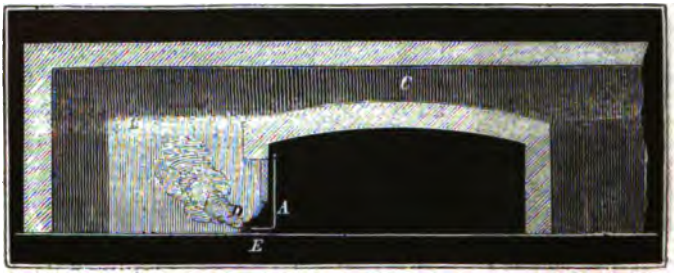
The naphtha is re-distilled from a vessel *I*, Fig. 67, after being mixed with a small quantity of water. Instead of the heat of a common fire, steam, in this case, is applied by the pipe *K*. An intermediate vessel *L* is placed between the still and the condenser, to retain the products of any sudden ebullition. The condensation and separation of the naphtha and water is conducted in the same manner as has already been described. The letter *l* shows how the cold water passes to the condenser, and *m* the exit-pipe of the heated water, after serving the purpose of condensation. The naphtha from this second distillation is then mixed with chloride of calcium, or quicklime, and subjected to a third distillation in a similar apparatus, when it is obtained perfectly colourless.

FIG. 67.



The *dead oil* obtained as the second product of the distillation of the coal-tar, is sold for the purpose of illumination on the quays of manufactories, railway-works, &c., and for preserving timber from decay when exposed to damp and water, as in railway-sleepers, piers and docks. It is also employed as a solvent for pitch, in which case it makes a valuable varnish, for coating wood and iron-work exposed to the weather, and lastly, for the manufacture of a very superior *ivory-black*. The arrangements for making the ivory-black are very simple. The dead oil, which is kept in a large reservoir, is heated by means of steam, to render it more fluid, so that it may flow through the pipe *A*, Fig. 68, more easily, and ultimately arrive at *D*. It is ignited at this point, and the lamp-black which results is deposited in long galleries, into which it passes through the

FIG. 68.



flue *C*. The large chamber *B* is constructed with the view of preventing occasional explosions extending into the galleries. Fig. 69 shows the end-view of the burners *E E*.

FIG. 69.

The pitch after having become hard, is ground under edge-stones, and mixed with small coal in the proportion of 1 to 4. The mixture of coal and pitch is carried up into a large hopper, from which it gradually passes into the receivers *M M M*, Fig. 70. At the bottom of these receivers, a pair of plain rollers *O*, Fig. 71, are kept in motion by the shaft *N*, Fig. 70, and by this simple contrivance, a regular supply is thrown into the retort *R*. An Archimedean screw *Q*, Fig. 71, is also made to revolve inside the retort, by the shaft *W*. The retort is maintained at a dull red heat by the hot air in the flue *T*, and the fuel passes through the whole length of the retort, which

FIG. 70.

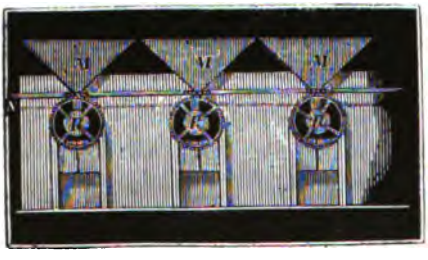
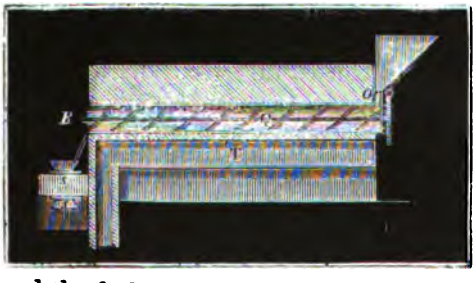
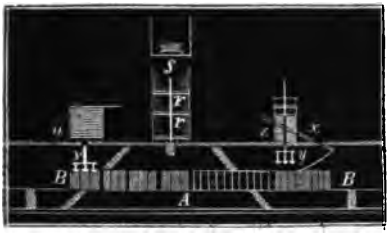


FIG. 71.



is about 15 feet long, in about three minutes. The mass of coal and pitch is discharged at the opposite end of the retort in a pasty state, and carried by an endless chain into the receiver *S*, Fig. 72, where it is kept in motion by the arms *r r*, so as to prevent it hardening into lumps. From this cylinder or receiver it runs into large moulds, where it is subjected to a heavy pressure in the following manner. *A* represents a moveable oval table, upon which the moulds *B B* are fixed. *S* the vessel which receives the fuel paste, *u* and *x* two cylinders similar to those of a steam-engine, but worked by water, *v y* the pistons, to which two rams are attached, each having six arms that fit accurately the moulds *B B*, and *z* is a lever worked by means of the motion of the piston *y*. The moulds are filled from the vessel *S*, as the table is made to revolve by the movement of the lever *z*. As the moulds approach the cylinder *u*, the piston descends and compresses the fuel with an enormous pressure, and after the piston rises, another set of moulds take their places, while the piston *y* of the cylinder *x* having descended at the other end of the table, the six bricks are forced out of the moulds, and are received below ready to be stamped with the maker's name. The machinery and the whole arrangements are exceedingly beautiful, and the accompanying sketch is only intended to convey an idea how the process is effected, without showing all the details of the mechanism.

FIG. 72.



The analysis of this fuel gave the following results:

Carbon	76.60	Coke { Carbon	61.67
Hydrogen	5.15	Coke { Ash	7.08
Nitrogen	1.54	Volatile matter	31.25
Oxygen	9.63		
Ash	7.08		100.00
	100.00		

The following table shows the composition of several specimens of artificial fuel, as ascertained by the officers of the Admiralty investigation.

Locality or name of coal.	Spec. grav. of fuel.	Carbon.	Hydrogen.	Nitrogen.	Sulphur	Oxygen.	Ash.	Percentage of coke left by each fuel
Warlich's patent fuel. .	1.15	90.02	5.56	trace	1.62	included in ash	2.91	85.1
Livingstone's steam fuel.	1.184	86.07	4.13	1.80	1.45	2.08	4.52	—
Lyon's patent fuel. . .	1.13	86.36	4.56	1.06	1.29	2.07	4.66	—
Wylam's „ „ . . .	1.10	79.91	5.69	1.68	1.25	6.63	4.84	65.8
Bell's „ „ . . .	1.14	87.88	5.22	0.81	0.71	0.42	4.96	71.7
Holland and Green's . .	1.302	70.14	4.65	1.15	—	—	13.73	—

The pitch employed in the manufacture of the patent fuel possesses a specific gravity of 1.01016, and yielded the following analytical results:

Carbon . . .	73.56
Hydrogen . . .	8.08
Oxygen . . .	17.79
Ashes	.57
	100.00

It contained no hygrometric moisture, and Wylam's patent fuel only 0.86 per cent.

A glance at the above composition of the pitch proves how valuable the substance must be in the manufacture of a fuel destined for raising steam on board steam-vessels. The large proportion of hydrogen and oxygen, add materially to the amount of heat it will evolve, and the facility of its combustion. And it is obvious, that a fuel manufactured from this substance in proper proportion, with a suitable small coal, will far surpass any natural coal for steam purposes.

For some years past the pitch produced from the distillation of gas-tar has been accumulating to such an extent, notwithstanding its application to patent fuel, as to be a very serious burden to many of the naphtha manufacturers, and in order to get rid of it they have at length adopted a plan of converting it into coke and obtaining an additional quantity of pitch- or dead-oil. This process is carried on in fire-brick ovens from 4 to 6 feet square by about 3 feet high, arched over at the top, from whence a large iron pipe carries off the very heavy vapours, which are easily condensed. The ovens have two doors opposite each other on either side; they are heated from below, and when red hot a charge of pitch is introduced and distilled for several hours, the doors being closed. When the charge is worked off, the doors are opened, the pitch-coke removed, and air allowed to enter the kilns for some time, in order to burn off the thick coating of coke which has

been deposited upon the sides and arch of the ovens from the decomposition of the tar vapours. The heat thus generated keeps the walls at a red heat, and but little additional fuel is required to work off the following charge. The pitch-coke thus obtained is very dense and hard, and much prized by iron-founders and others on account of the small quantity of ash which it leaves and its freedom from sulphur.

Warlich's Patent Fuel.—Warlich's object is to render patent fuel more capable of sustaining the heat to which it is subjected on board steam-boats, particularly in hot climates.

He employs the bricks made of the usual materials, but adds a little common salt or alum, to prevent the evolution of too much smoke, and subjects them in retorts to a temperature of 400° F and upwards, for six to eight hours, while he assists the evolution of the gaseous matters by an exhausting apparatus.

Fig. 73 shows an elevation of a retort and furnace, and Fig. 74 a plan.

FIG. 73.

FIG. 74.

Fig. 75 is a transverse section of one of the retorts and furnaces. Fig. 76 is the longitudinal section of the retort; *a* is the chamber

FIG. 75.

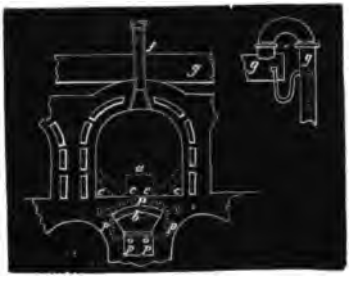
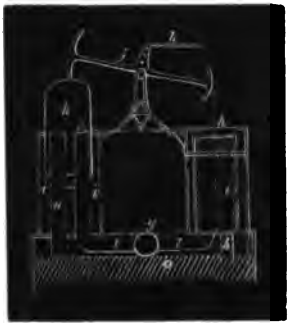


FIG. 76.

in which the fuel is placed, and which is fitted with sliding doors; *c c* are the rails for the carriages, which have several shelves, on which the manufactured fuel is placed; *e*, eduction ways for the gases expelled from the manufactured fuel, which by means of a dip-pipe *f* convey the products into the main *g*, as is practised in the manufacture of coal-gas.

Fig. 77 shows a section of the exhausting apparatus, which consists of two cylinders *h h*, open at bottom, working in vessels *i i* containing water. The motion communicated to the beam *j* by the connecting-rod *k*, alternately raises and lowers these cylinders; *g* is the main, with two branch-pipes *l l* and valves *m m* opening upwards; *n n* are two dip-pipes into the tank of water *o*. The products pass from the chamber retort into the main *g*, thence into the vessels *h*, whence they are forced below the water in the tank *o*.

FIG. 77.



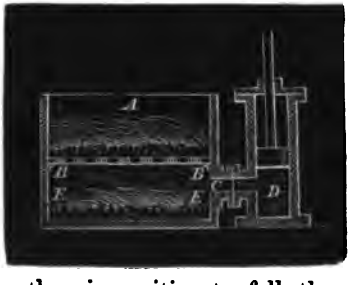
The fuel is heated in the chamber by a current of hot air, which passes into the retort through the openings *p p*.

The apparatus is similar to that employed at Bagilt for condensing lead-fume suggested by J. D. Stagg.

The following method is adopted at Blanzy for working up the small coal which accumulates in large quantities at the mines.

Fig. 78 represents the machine by which the pyrites and other impurities are roughly separated from the coal. *A* is a large vat, separated into two compartments by a metal sieve *B B*, and communicating with a pump *D* by means of a large tube *C*. The vat is ⅔ filled with water, and the coal thrown on the metal sieve. The agitation produced by the working of the pump causes the pyrites and other impurities to fall through the sieve to the bottom of the vat. The coal, after draining, is crushed between rollers similar to those used in bone-mills, in order to render the pieces more uniform.

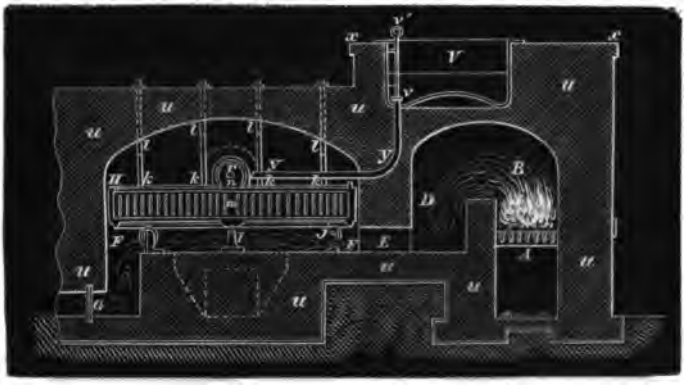
FIG. 78.



The coal thus prepared and dried is mixed with 7 or 8 per cent

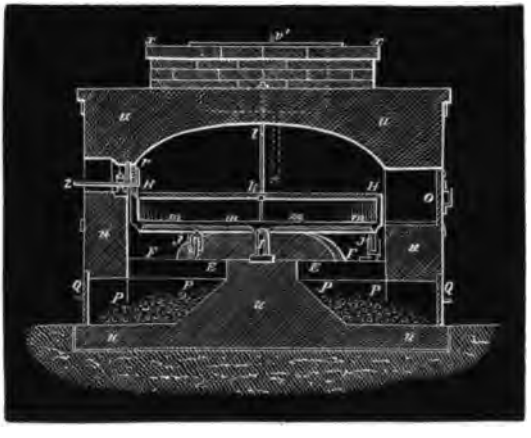
of tar in the cold, and made into bricks by means of the following machinery. In Figs. 79 and 81, *A* represents the ash-pit of a furnace, *B* the metal plate between the door *C* and the grates *B*, *D* an arch to depress the flame so that it shall pass under *E* and

FIG. 79.



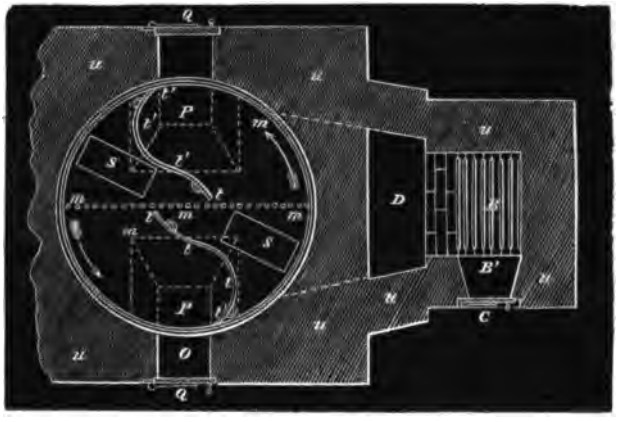
spread itself over an extensive surface in *F*, where it heats a metal cistern turning on a pivot *I*. The smoke passes off by a chimney *G*; the metal cistern *m m* is driven by a pinion *r*, which works into the toothed edges *H H*. A rake *k k k* is suspended by the rods *k l*, which are built into the solid masonry *a a*. *V* is a boiler heated by the arch *D*, and a valve *v*, at the bottom, is opened or closed by the rod *v'*, to allow the tar to flow through the pipe *y y*. The coal prepared as already detailed, is thrown into the furnace by the opening *O*, Fig. 80, and the rakes spread it evenly over the surface of the metal

FIG. 80.



cistern. The tar is admitted by opening the valve *v*, and as it flows through a pipe *n*, running the whole length of the rakes, it is more perfectly mixed with the coal, and a smaller quantity is sufficient to make a uniform mass. When the cistern is in the position indicated by the arrows, Fig. 81, the two scrapers *t t t t* are

FIG. 81.



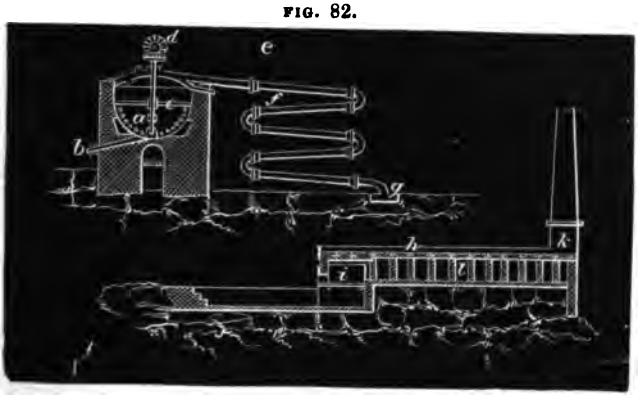
lowered together, and they carry the coal forward; when the cistern has made ⅔ of a revolution, the two trap-doors *s s* are opened, and the mass falls down into the receptacles *P P*. This warm mixture of coal and tar is removed through the doors *Q Q*, and pressed into bricks by an hydraulic machine.

Another modification consists in filling a series of moulds fixed on a moveable table, and by a mechanical contrivance forcing the bricks out of the mould at the same time.

Mr. Wood proposes to make artificial fuel by mixing either coke or coal sufficiently small, in a heated state, with tar or pitch, in a common pug-mill, after which the mixture may be moulded in the ordinary manner.

Chagot's Artificial Fuel.—In the process for the manufacture of artificial fuel, by MM. Chagot and Co., of Châlon-sur-Saône, common coal-tar is mixed with small coal or carefully-selected peat, in the proportion of 10 to 50 of the former to 100 of the latter. A certain quantity is then introduced into the still, shown in Fig. 82, where *a* represents the body of the still, with a discharge-pipe and cock *b*, and an agitator inside *c*, driven by machinery at *d*. The cover is double, the inner being composed of

FIG. 82.



sheet- and the outer of cast-iron, with a condensing worm *f*, supplied with cold water from a cistern at *e*, and discharging the products of distillation at *g*. The usual products, naphtha, &c., distil over, leaving the pitch behind, which is run off, allowed to cool, and reduced to powder.

This pitch is ground and mixed with small coals, which have been previously dried on a flat surface at *h*, heated from below by the flues *l*. As soon as the material has been sufficiently incorporated, and the whole rendered somewhat soft by the heat, it is removed into moulds, and subjected to hydraulic pressure.

This is a very simple and obvious method of working up these waste products.

The following patent process for consolidating refuse coal-dust appears of great value, and is the invention of Mr. Bessemer, from whose specification the following description is borrowed.

It is found that when coal or coal-dust is heated up to a temperature of 500° or 600° F., it becomes softened, the bituminous portions undergoing a degree of fusion sufficient to cause the small pieces to adhere together. It is this peculiar property of partial fusion in coal that Bessemer makes use of as a means of forming, by pressure, consolidated blocks or masses of coal, possessing the characteristic properties of the coal from which they are formed, but which have the additional advantage of being in pieces of uniform size.

Instead of forming the soft coal into large unwieldy masses, as usually practised in the manufacture of artificial fuel, and which require to be broken into pieces before use, producing much small coal or dust, it is made at once into small cylindrical bricks,

of a size well adapted to furnaces or domestic use, while the trouble and loss of breaking is prevented, and a most convenient fuel obtained.

The machinery or apparatus employed for this purpose is represented by the drawings on Plate XVI, where

Fig. 1 is a longitudinal elevation of a furnace, and an end elevation of pressing machinery.

Fig. 2 is a plan of the same.

Fig. 3 is a longitudinal section of the furnace on the line *a b* of Fig. 2.

Fig. 4 is a cross section of the furnace, and longitudinal section of the pressing machinery on the line *c d* of Fig. 2.

Fig. 5 is a side elevation of the pressing machinery, and an end elevation of the furnace; and

Figs. 6 and 7 are details of the travelling chain-bed, on a larger scale.

In this apparatus, the furnace for heating and softening the coal, the machinery for pressing it, and the steam-engine which produces the required motive power, are all combined, and constitute one apparatus; and as the products of combustion will pass off from the furnace at a high temperature, it is intended that this surplus heat shall be applied to the generation of the steam required by the engine; for which purpose, a steam-boiler, provided with suitable flues, should be set as near as convenient to the end *a** of the furnace *a*, where it will be perceived that an opening is left at *b*, Figs. 1 and 3, for the purpose of allowing the heated matters from the furnace *a* to pass into the flues of the steam-boiler, the arrangement of which is so well understood as not to require detailed description.

The furnace *a* is of the reverberatory kind, and has a fire-place at *c*, provided with fire-bars *d*, and doors; *e f* is an endless chain-bed, of peculiar construction, passing over polygonal drums *g*, mounted on axes *h*; the horizontal position of the chain *f* is ensured by small iron rollers *i*, which support it at short intervals; the rollers *i* are provided with axes, which work in iron sockets let into the side-walls of the furnace; as also the axes *h** of the polygonal drum *g**. The chain-bed consists of a number of iron bars of about 30 inches in length, notched on each side, and fitting into each other in a similar manner to a common hinge-joint, and like the hinge, it has a pin passing entirely through it, and thus forms a joint capable of folding over the

Fig. 1.

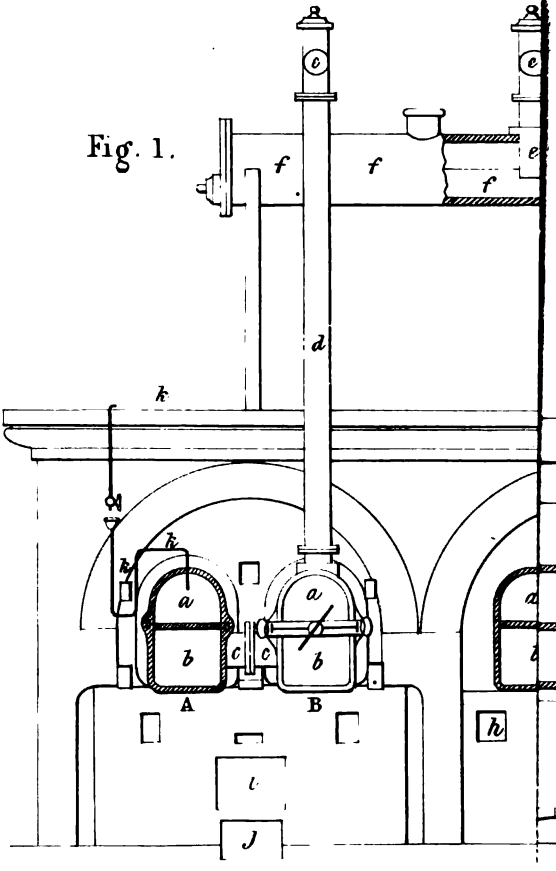


Fig. 2.

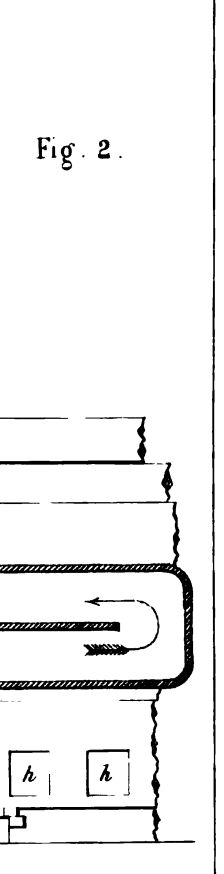
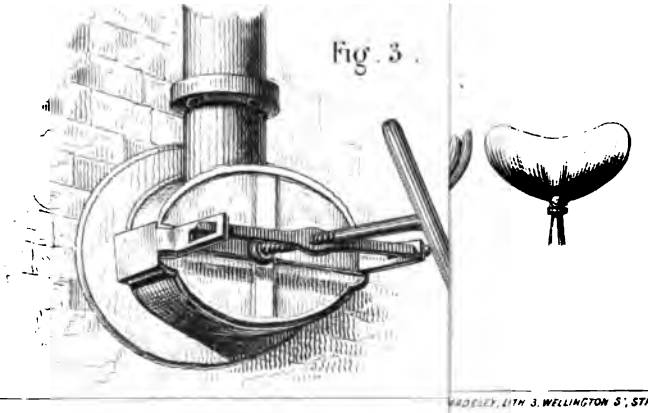


Fig. 3.



WADELEY, LITH 3, WELLINGTON S', STRAND

polygonal drums *g*, and also of presenting a nearly flat surface on the upper side (see Figs. 6 and 7, where a part of the chain-bed is shown on a larger scale). Near the end of the furnace farthest from the fire, a hopper *j* is fixed, into which the small coal is thrown; this hopper has a roller *k*, with leaves projecting from it, working in a cylindrical part formed in the hopper. The roller *k* is mounted on a shaft *l*, which turns in bearings formed in the bosses cast on the sides of the hopper *j*. The shaft *l* is farther supported by a plummer-block *n*, and carries on its outer end a drum *m*, which receives motion from the strap *o*, and causes a regulated quantity of the small coal to pass from the hopper through the opening *p*, and fall upon the endless chain-bed in a thin layer; the motion of the chain-bed in the direction of the fire-place *c* will bring the coal along with it, and discharge it into the hopper *r*. To prevent any portion of the coal that may stick to the chain from being carried back again, a scraper *s* is made to press its edge against the lower part of the chain; the scraper is mounted on an axis, and has a lever and ball *q*, the weight of which presses the edge of the scraper against the chain. It will be seen that the fire-bridge *t* rises sufficiently high to protect the chain from the violent action of the fire, and it at the same time forms one side of the hopper or receptacle *r*.

A break is shown in the drawing, to denote that the furnace and chain-bed are to be made longer than is there represented: from 30 to 40 feet of bed will be found to answer well.

When a fire is made in the fire-place *c*, the heat will be reverberated on to the thin stratum of coal upon the chain-bed, which as it first enters from the hopper is subjected to the lowest temperature of the furnace, and brought progressively into the hotter part, near the fire-bridge; while new portions of coal are deposited upon the chain-bed, as it passes under the hopper *j*, which are in turn carried towards the fire-bridge. The increased temperature to which it is thus subjected will cause the coal to soften, and commence to give off some of its volatile constituents, which when inflamed, add to the action of the furnace.

The extent to which the fusion of the coal is carried may be regulated by the speed at which the chain moves, and also by the state of the fire: the small coal being thus softened by heat, and delivered in a regular and continuous stream into the hopper *r*,

is then to be pressed by an apparatus constructed in the following manner:—A, is a strong bed-plate or frame, forming a sort of rectangular box having a flange A^1, extending around the upper side, and another flange at the lower side connected to the upper one by ribs A^2, and dividing it into panels; externally, upon the upper flange of the bed-plate, are bolted the plummer blocks B, which support the trunnions of an oscillating steam cylinder C, which, with its steam-pipes, slide-valve, and valve-gear, may be constructed in the ordinary way; D is a one-throw crank of great strength, working in plummer blocks E, and carrying on one end the fly-wheel F. The piston-rod G of the steam-cylinder is connected to the crank by a jib-head G*; there is also connected to the same crank-throw a connecting-rod H, having a double jib-head, so as to take hold of the crank on each side of the piston-rod G; the other end of the connecting-rod H is jointed at H* to the cross-head I, which moves in slots formed in the guides J J, which are bolted to the upper flange of the bed-plate A. One end of the bed-plate A passes through the lower part of the furnace *a*, and has bolted to it at that part a massive piece of iron K, with two cylindrical holes bored entirely through it parallel to each other, and which for distinction are termed the pressing-cylinders; the piece K is held firmly in its place by bolts, and is farther prevented from moving by projecting pieces K*, which abut against the flanges of the frame A; the upper side of the piece K has an opening or hopper *r** through which the softened coal falls into it. There are two plungers L L fitted to the cylinders, and keyed into the cross-head I, so that the revolution of the crank by means of the connecting-rod H, and guides J J, will produce a reciprocating motion of the plungers L L. The crank D has keyed upon it at one end a bevelled pinion M, working into a bevelled wheel N, which is mounted on a shaft P, supported by plummer blocks Q Q; and at the other end of the shaft P there is a spur-wheel R in gear, with another wheel S on the axis *h* of the polygonal drum *g*. This axis *h* also carries a drum T, over which the strap *o* passes and communicates motion to the roller *k*, and thereby regulates the supply of coal upon the chain-bed. The action of the apparatus will be as follows.

Steam having been got up in the boiler by a fire made temporarily under it for that purpose, and the fire lighted in the fire-place *c*, the working of the apparatus will commence whenever

a communication between the boiler and steam-cylinder is opened, the rotation of the crank-shaft will put in motion the bevel-wheels M and N, and the shaft P; and by means of the spur-wheels R and S, the shaft *h* of the polygonal drum *g* will receive a rotatory motion much slower than the crank-shaft, by reason of the difference in the diameter of the wheels made use of for that purpose, and thus a slow travelling motion will be given to the chain-bed. The shaft *h* also carries a drum T, which, by means of a strap, gives motion to the drum *m* and feeding-roller *k*, and thereby causes a regular supply of small coal to fall upon the chain-bed, as it passes under the hopper; the reverberated heat from the crown of the furnace acting on the thin stratum of coal upon the bed will cause a partial fusion or softening of its bituminous parts before arriving at the hopper *r*, into which it falls. While this action is regularly and continuously going on, the crank-shaft of the apparatus will, by means of the connecting-rod H and cross-head I, give a reciprocating motion to the plungers L L, which work in the cylinders K, and pass along the lower part of the hopper *r**, and push before them the softened portions of coal into that part of the cylinders marked K^1; the extreme distance to which the end of the plungers move is indicated by the letter Z. When the crank commences its backward movement, the plungers will also recede until they assume the position represented in the drawing. While this retrograde movement of the plungers is taking place, some portions more of softened coal will have fallen down from the endless chain-bed, and have been deposited in the hopper and upon the plungers; but as the plungers recede, as before stated, into the position shown in the drawing, the coal which has fallen upon them will fall off again into the space occupied by them; and when the plungers again advance, a fresh portion will be forced into the cylinders K^1, but as the plungers move forward an equal distance each time, the portion of coal pushed forward will be forced against the portion of coal left there by the former stroke of the plungers, and not only will it be forced against it, but it will move it farther along the cylinders K^1 until the last portion occupies the place of the former one; and thus, by the continued action of the plungers, fresh portions of coal will be forced into the cylinders K^1. It will be observed that the cylinders K^1 are open at the end, and it is towards this open end of them that each successive portion of coal is forced by the plungers; the friction of

the mass of coal in sliding along the cylinder is very great, and the resistance thus opposed to the motion of the plungers L L causes a powerful compression of the fuel to take place, which is finally projected from the end of the cylinders in a solid and compact state, as shown at W.

It has been already stated that the surplus heat of the reverberatory furnace may be applied to the production of steam for supplying motive power for the working of the apparatus, and in some cases it may be deemed advisable to heat the coal by this process sufficiently to ignite it, and cause a combustion of the more volatile portions, by which more heat will be communicated to the boiler, and a fuel produced possessing many of the peculiar and valuable properties of coal, but at the same time not possessing sufficient bituminous matter to cake together when used in a furnace or common fire-place, and from the same cause not producing a dense black smoke, and capable of being used in many cases where coke is now employed.

The apparatus described above is preferred when a fuel differing very little from ordinary coal is required, and the heat is only sufficient to cause the necessary adhesion amongst the small pieces and dust. If more gaseous matter is to be removed, or different kinds of coal refuse to be mingled and heated so as to produce a fuel differing from coal and more analogous to coke, the following arrangement of apparatus is employed.

In order that the volatile products of coal given off while undergoing the softening process, as well as those portions which are purposely expelled in order to modify the quality of the fuel, and enable it to be made in lumps of definite lengths, an apparatus is constructed in which the retort furnace for heating the small coal, the pressing machine for solidifying the fuel, and the engine for producing the motive power, are combined so as to constitute one apparatus, as represented in the drawings on Sheet B Plate, page 144, and Figs. 83 and 84, where—

Fig. 1, Plate, page 144, Sheet B, is a longitudinal elevation with the steam-cylinder omitted.

Fig. 2, a plan of the same.

Fig. 83, shows, firstly, a longitudinal section on the line A B of Fig. 2, with the position of the steam-cylinder; and secondly, a longitudinal section on the lines C D, of Fig. 2, Plate, page 144, and E F, of the sketch below.

Fig. 84, shows various sections of the pressing apparatus at different stages of the pressing process.

FIG. 83.

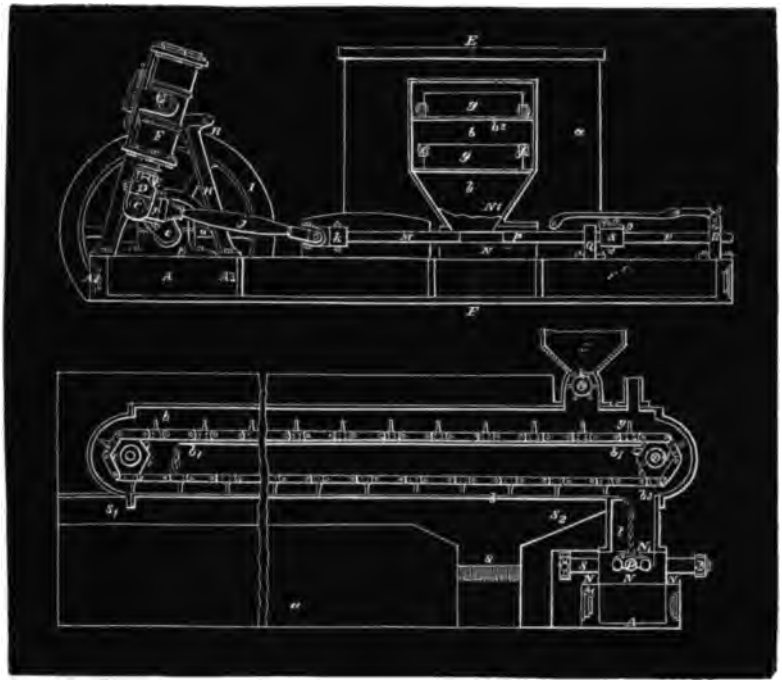
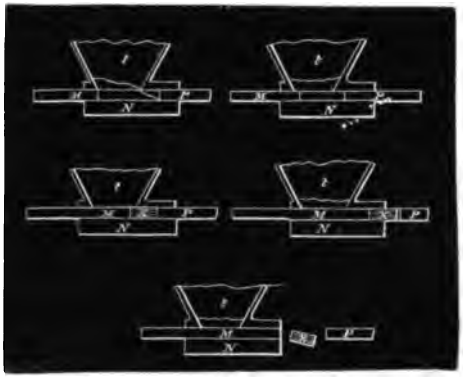


FIG. 84.



In the furnace *a* is fixed the rectangular vessel or retort *b*, which

is shown broken through, to indicate that its length should be greater than represented in the drawings; about 30 feet in length will be found to answer well; it should (for convenience of putting up) be made in three lengths united by flanges, and the joints made tight with iron cement; one end of this retort projects from the furnace, and overhangs a part of the pressing apparatus. The retort has a partition b^1 extending nearly the whole length of it, and in a tangent line with the upper surface of the polygonal drums *c* and *d*, over which two endless chains *e* and *f* are made to pass (see Fig. 2 on Plate, and Fig. 84); the chains *c* and *d* are connected together by broad plates of iron *g*, with flanged ends, which are riveted at *h* to the single links of the chains; the edge of the plates *g*, which project beyond the chains, is bevelled so as to form a scraper; the polygonal drums *c* and *d* have projections *i* formed upon them, which fall into the spaces between the double links of the chains, and ensure the motion of them when the drums *c* and *d* are turned round. On the upper side of the retort there is fixed a hopper *j*; the lower part of the hopper, in which the coal-dust or small coal from which the fuel to be formed is placed, is made to fit closely to the leaves or ribs projecting from the feeding-drum *k*; there are bosses *l* formed on the sides of the hopper, in which the shaft *n* of the feeding-drum revolves; there are also bosses (not seen in the drawings) formed on each side of the retort for the axis of the polygonal drum *c* to revolve in; and on the outer projecting part of the retort are formed two other bosses *o* and *p* for the axis *r* of the polygonal drum *d* to revolve in. One end of this axis is elongated, and passes through a stuffing-box formed on the boss *p*, so that none of the volatile matters within the retort can make their escape at the part through which motion is transmitted to the interior.

The action of this part of the apparatus is as follows:—A fire having been lighted in the fire-place *s*, the heat passing under the retort escapes with the products of combustion at the open end of the flue s^1, where it may be made to circulate about a steam-boiler, for the purpose of generating the motive power required to work the apparatus. It will be preferable to set the retort so that the heat may ascend a narrow space between the sides of it and the brickwork of the furnace. An enlargement of the fire-chamber is shown at s^2, for the purpose of transmitting radiant heat to the under-side of the projecting part of the retort. The temperature of the furnace having brought

the retort up to a heat approaching redness, the feeding-drum is put in motion, when the small coal or coal-dust will be deposited upon the shelf b^1; but the motion of the chains and scrapers in the direction indicated by arrows, will move it along the shelf; and as each scraper comes in turn under the feeding-drum, the coal which has fallen between each of them will be carried forward to the end of the shelf b^{1*}, off which it falls on to the lower and hotter part of the retort, and, as before, occupies the space between the scrapers. It will be observed, that the entire weight of the chains and scrapers rest on the bottom of the retort, so that by their constant passage over it, the coal is prevented from sticking to it, and rendering its interior surface uneven. The action of the scraper not only impels the coal forward, but turns it over as it passes along, so as to present fresh portions of it to the heated surface of the retort, and thus ensure an equal effect on the whole of the coal-dust, which becoming softened, is moved in that state over the opening b^3, in the lower side of the retort, and falls into the receptacle *t*, where it is submitted to the following operations.

A is the foundation-plate or framing of the pressing apparatus: it is a sort of shallow box, having a flange A^1 around its upper edge, connected to the lower flange by vertical ribs A^2, which divide it externally into panels, the interior portion of the framing being also divided by ribs A^3, by which its strength is increased. Upon the flange A^1 are bolted the plummer-blocks B, which support the crank-shaft C, made very strong to withstand the strains to which it is subjected. The crank has only one throw formed on it, in the centre of which is attached, by a gib-head D, the piston-rod E of the oscillating steam-cylinder F. The steam-cylinder, with its induction and eduction-pipes, side-valve, and other necessary appendages, may be constructed in the usual way. These parts have been omitted in all the figures, except in Fig. 83, where the steam-cylinder is represented in the position it would occupy at the particular part of the crank's motion there represented. It will be observed, that the steam-cylinder is placed, with its axis, in a line vertically over the crank-shaft, and is there supported by trunnions G, working as usual, in plummer-blocks bolted to the two frames H H; these frames have lugs cast on them at H*, through which stretchers are to pass in order to steady them; the frames H are bolted at foot to the flange A^1 of the bed-plate.

In order to regulate the motion of the apparatus, the fly-wheels I I are keyed one on to each end of the crank C. A stout connecting-rod J is made with a double gib-head J*, to embrace the gib-head D, and thus to receive motion from the same crank-throw. The other end of the connecting-rod J is jointed by a gib-head and pin to two lugs K*, which project from the stout cross-head K; the ends of this cross-head slide in guides L L, which are secured by bolts to the flange A^1 of the bed-plate. There are three plungers M M M keyed into the cross-head K, and work in cylindrical holes, bored truly through the massive block of iron N; this block N is bolted to the bed-plate by a flange N*, and is keyed up between steps Z, cast on the bed-plate. The upper part of the cylinder block N has a large opening N^1 made in it, through the bottom of which the plungers M move; and immediately over the opening N^1 is the receptacle into which the softened coal falls from the retort. The cylindrical holes in the block N have another set of plungers P P P, working in the opposite end of the holes to that occupied by the plungers M M M. On the flange A^1 of the bed-plate are bolted two guide-bars Q and R, having holes bored in them of a size to fit the plungers P P P, which are made long enough to work through both these guides; so that when the plungers P P P are entirely withdrawn from their respective cylinders in the block N, they will be so guided as to re-enter them without difficulty. The plungers P P P are keyed to a cross-head S; on the ends of the cross-head S there are fitted with gib-heads two long connecting-rods T (see Fig. 2, as they are omitted in the rest of the figures). The opposite ends of the connecting-rods T are provided also with gib-heads, and work on crank-pins U, which project from one of the arms of each fly-wheel I I. These crank-pins U U are so placed with reference to the central crank-throw C that the latter forms an angle of 45° to the crank-pins; that is, the one is one-eighth part of a circle in advance of the other, and thus the action on their respective plungers will be such that they will alternately approach and recede from each other at each end of their respective strokes.

It has already been described how the small coal is made to traverse the retort and be deposited in the receptacle. The means whereby the requisite motion is given to the chain and feeding-drums is as follows:—Over one of the fly-wheels I a strap is passed, which works upon a drum V on the shaft W; on this

shaft W there is a worm X which works on the upper side of the worm-wheel Y, which is keyed on to the shaft *r* of the polygonal drum *d;* the shaft W also carries another worm 1, which works into the lower side of the worm-wheel 2, keyed on the axis *n* of the feeding-drum. The shaft W is supported in bracketed plummer-blocks 3 3, which project from and are bolted to the side of the retort, so that whenever the fly-wheel is put in motion, the intermediate wheels and shaft last described will transmit the requisite motion to the scrapers and feeding-drum. From previous descriptions, it will have been understood how the steam-piston, acting upon its crank, will put in motion the whole apparatus, which will be regulated by the fly-wheels, and in what manner the cross-heads K and S will be acted upon by their respective connecting-rods, and how the set of plungers M M M, and plungers P P P, are made to reciprocate in their respective ends of the block N; but in order to show more clearly the way in which they are made to approach and recede from each other five sectional drawings are shown on Fig. 84, by which the relative positions of the two sets of plungers, with reference to each other at different parts of their stroke, will be seen; and to render this explanation more clear, we may suppose the operation to commence when the crank-throw C and its connecting-rod are in a horizontal position, and the plungers M M M withdrawn as far as possible from the block N. This position is represented in the Fig. marked 5, where it will be seen that the fuel in an uncompressed state has fallen down and occupies the space in the front of the plungers M. If we now make one-eighth part of a revolution the plungers M will be moved forward a little, as shown at 6 and in Fig. 83, where it will be seen that the crank-pins U U have risen up to the horizontal line and brought the plungers P nearer towards the centre of the block N; if we now give another eighth of a turn to the crank, the plungers N will have advanced a considerable distance, being at half-stroke, and at the same time the plungers P will have receded into their starting position, as represented at 7. Here it must be observed that the soft coal, which was carried forward by the plungers M, is compressed between the opposing ends of the two sets of plungers. In this position of the plungers there is a small space at Z, (*vide* 7), where any surplus quantity of coal may squeeze out before it is made to enter the close part of the cylinder, after which they will approach a very little nearer to each

other and thus give the final pressure. If another eighth of a revolution is now made, the relative positions of the crank and crank-pins will give a quicker motion to the plungers P, which will commence receding from the other plungers M, and thus leave no pressure on the solidified lump of coal X; were not the pressure thus relieved, the lump of coal as it merges from its cylindrical hole in the block N would be broken, there being no longer any circumferential support for it. This position of the apparatus is shown at 8. Another eighth of a turn will complete a single stroke of the plungers M, and have entirely expelled the block of coal X, which is represented as falling down at 9; the plungers P have receded still farther, and allow ample space for the block of fuel to fall. Another eighth of a turn will commence the return stroke of the plungers, and by following on in the same way until one complete revolution is performed, the respective plungers will again have resumed the position represented at 5, and be ready to renew the operation.

If three plungers are made use of, as here represented, three blocks or cylinders of fuel, of equal length and diameter, will be formed at each complete stroke of the engine. As there is a tendency in the block of fuel to stick to the plungers M, a detaching frame is placed at the end of the machine where the blocks are expelled. 4 4 are thin bars of iron fixed on an axis 5, the ends of which work in lugs 6 on the guide-bar R; the other end of the bars 4 4 are connected together by a rod 8, and upon the cross-head S there are bolted two small frames 9 9 which carry rollers 10; upon these rollers the bars 4 4 rest, and when in the position shown in Fig. 83, the bars are supported a little distance above the plungers P; but when the cross-head S moves backward, and allows the blocks of coal to be projected outward by the plungers M, then the roller will pass under the inclined part of the bars 4*, when they will descend by their own weight, and the rod 8 will come in contact with the blocks of coal and detach them from the ends of the plungers; if they should adhere, the reverse motion of the cross-head S will again raise up the bars 4 in readiness for a repetition of the process.

From what has been before stated in reference to the softening process by heat, it will have been understood that the coal-dust may be made to traverse the shelf b^1, where it will receive a preparatory heating, and afterwards traverse the bottom of the retort

so quickly as to produce such a light effect upon the bituminous portion of the coal as only to soften it a little and render it fit for the operation of compressing into solid lumps, possessing the general properties of the coal from which it was produced. But one of the great objects of this apparatus is to alter and modify the composition of the resulting fuel by driving off certain of the volatile constituents of coal, and thereby rendering such fuel more fitted for certain processes in the arts than ordinary coal. To effect this object the speed of the feeding and polygonal drums may be regulated so as to subject the coal to any assigned period of operation, and the intensity of the fire being also regulated, the extent to which the distillatory process is carried will be under perfect control; the gaseous matter given off from the coal as it passes into the hottest part of the retort over the fire-plate *s*, will have to pass over the surface of the coal which is advancing in that direction, and help to heat it, while it also assists in transmitting heat to the under side of the shelf b^1. It will ascend through the opening b^1*, and pass along over the coal-dust spread upon the shelf, and farther assist in heating it, and finally make its escape through the pipe *u*. This pipe should have an elbow descending in the manner usually adopted in gas-works, and known as the hydraulic main. In this vessel the liquifiable portion of the volatile matters will be condensed, and the gas may be passed into a gasometer, where it may be stored and used. The fuel resulting from this partial distillatory process will be found to be less fusible in the furnace than ordinary raw coal, and consequently the caking in the furnace will be prevented.

In order to facilitate the evolution of gaseous matters from the coal at as low a temperature as possible, and to increase the density of the compressed fuel, an air-pump, constructed in the manner generally employed for exhausting sugar vacuum-pans, is used. The pump is connected with the pipe *u*, Sheet B, Plate, page 144, and by the application of steam or other motive power the retort is kept in a state of exhaustion, which should, if possible, be equal to 24 or 25 inches of mercury in the barometer; the effect of this exhaustion is to cause the liberation of the gas from the cells and interstices of the fuel, and to render it more dense and compact when pressed. When the air-pump is used, the eduction valves must be made to communicate with the hydraulic main, so

that the gaseous matters pumped out may pass off into the gasometer.

Instead of applying fire direct to the under side of the retort, as shown in Sheet B, highly-heated steam may be used for the purpose of heating and softening coal, to be afterwards pressed into lumps or cylindrical pieces. For this purpose, a set of cast-iron pipes are arranged in a furnace in the same way as is now commonly used for heating air for hot-blast furnaces, and also for heating steam. Into one end of this series of heating-pipes, the waste steam of the engine is allowed to pass, and the pipes being kept at a red heat, the steam will acquire a very high temperature, and in that state is to be supplied to the interior of the retort for the purpose of softening the coal; in this case, the retort, which may be made in the same manner as that represented in Sheet B, but will not require any fire-place or flue beneath it, but should be enclosed in brickwork or other bad conductor of heat; the pipe which conveys the steam should enter at the hopper *t*, the steam escaping with the gases through the pipe *u* into the hydraulic main, where condensation will take place, the gases passing off to the gasometer.

In addition to the processes described above, the following plans have also been suggested or patented for preparing artificial fuel.

Bell proposes to use pitch, asphalte or bituminous matters and small coals in a pug-mill, whose knives and shafts are hollow, so as to be heated with steam, and then moulded.

Cobbold agitates peat in water by means of machinery, so as to separate the earthy matter, and allow the peat afterwards to subside.

Dobree proposes to heat ground small coals, breeze or cinders, and pitch, &c., in close vessels with high-pressure steam, which will so amalgamate the whole that they may be moulded.

Godwin proposes to make bricks from mud, or clay, ground up with pitch and coals; and

Geary to melt pitch, coals, tar, sawdust and clay together for the same purposes.

Holcombe proposes to run a mixture of tar, pitch, dead-oil, &c., over bricks formed of limestone or other porous materials.

Mohun mixes alum, nitre, peat coke, &c., in a pug-mill, and afterwards compresses them into moulds.

Oram uses tar, coals, mud, &c., and compresses them into moulds, after being previously carefully mixed and sifted.

Stirling uses the ordinary materials but exposes the bricks to a temperature of 250° F. afterwards.

Warlich heats his bricks in large kilns up to a temperature of 400° or 600° F., to expel all the gaseous constituents, exposing the square bricks, so as to make coke in the usual way.

Hill's process consists in distilling peat in the same way as wood, and mixing the residual charcoal with the hot pitch, so as to form lumps or bricks on cooling.

Lowe saturates dry blocks of peat with tar or other hydrocarbonaceous fluids in large cisterns, by means of heat.

Holland mixes gypsum, lime or cement with tar or small coals, and compresses the mixture into moulds.

Buckwell simply employs enormous pressure to form bricks out of small coal, or breeze from coke, while

Rees submits such materials in moulds to a temperature of 500° to 990° F., which partly melting, adhere on cooling and form solid masses suitable for use.

Brooman substitutes gutta percha as the binding ingredient when using the usual materials, while

Ransome employs a solution of silica in soda for the same purpose.

GASEOUS COMBUSTIBLES.

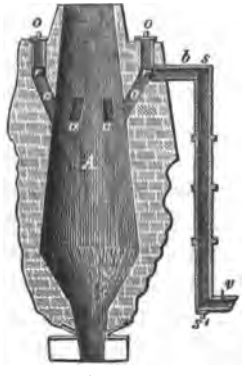
In the year 1812, a patent was granted to Aubertot for the application of the combustible gases escaping from an iron-furnace to metallurgical purposes, and in the year 1830 attempts were made at the Lead-works of Halsbrücke, near Freiberg, to employ the flame of coal-gas in cupelling the silver-lead; but neither of these attempts at introducing gaseous combustibles as fuel were followed up until the subject was carefully investigated by Faber du Faur, about sixteen years ago, at an iron-work in Würtemberg, the result of whose laborious experiments has now led to a very general adoption of the waste gases from iron-furnaces as fuel, and indeed to the production of gas to be specially applied for the purpose.

The property of burning with flame is common to most of the natural fuels, and is due to the evolution and combustion, at a

high temperature, of the combustible gases, carbonic oxide, hydrogen, carburetted hydrogen, &c.; but even those fuels which, like charcoal and coke, usually burn with little or no flame, may be made to afford combustible gas under peculiar circumstances—for instance, when ignited in large quantities, with a limited supply of air—when a large proportion of the carbonic acid at first produced becomes converted by contact with red-hot charcoal into carbonic oxide. Any solid combustible may thus yield gaseous fuel. As the process of dry distillation, in which the whole of the combustible gases may be obtained from fuel, involves too serious a cost in the extra firing to be applicable to the production of gaseous fuel, a plan of burning the solid fuel in large quantities, with the admission of a limited supply of air is resorted to, and a special apparatus or *generator* is employed for the purpose. In most cases, however, where gaseous fuel has been much employed, it is obtained as a waste product from blast furnaces, which has only to be collected in proper flues, and conveyed by pipes to the place of consumption. In the latter case, the mode of production is similar, although the chemical constitution of the gases from the two sources is not the same.

Waste Gases from Iron Furnaces.—The method of conducting away the waste gases from an iron-furnace, as carried out by Faber du Faur, is shown in Fig. 85.

FIG. 85.



At the proper distance from the throat of the furnace *A* (from 3 to 12 feet, according to its construction), several apertures *a a a* are made in the sides, from which flues lead to the annular flue *r r*, the latter being connected with the iron pipe *b* for conveying the gases to the place of consumption. The flow of gas can be regulated by the damper *v*, and above each aperture *a* is a moveable lid *o* for the purpose of cleaning the flues from furnace-dust. Closed apertures at *s* and s^1 admit of the pipe being cleaned.

Mr. Budd, of the Ystalyfera Iron-works, Swansea, applies the heated gases which escape from the anthracite furnaces for heating the blast and raising steam in the blowing-engine. In his arrangement, the excessive heat of the gases only is employed, as they are not

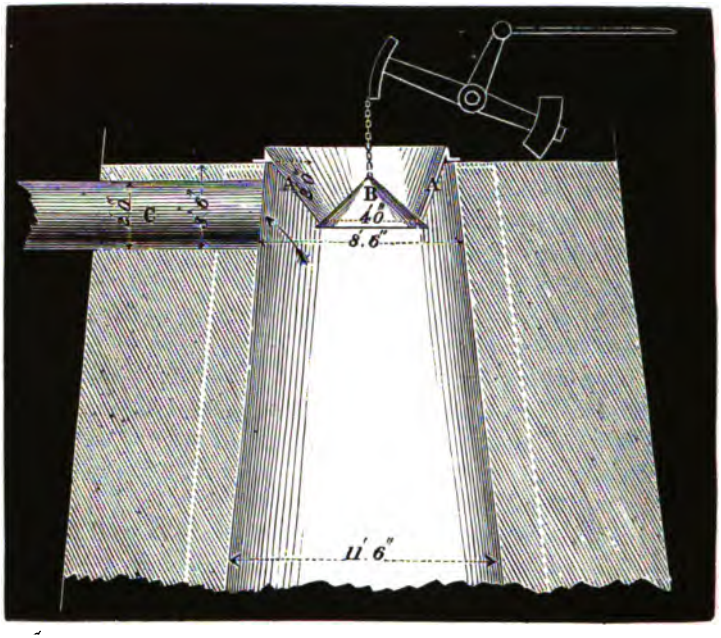
ignited, but simply passed over the pipes which convey the blast, and through the pipes which pass through and over the boilers. A similar arrangement to that shown in Fig. 85 is adopted, the apertures being, however, only about 3 feet from the mouth of the furnace, and the hot-air pipes enclosed in an oven on a level with the outlet-pipe *b*, and the gases drawn away by a small chimney in connection with the ovens.

At Coltness Iron-works in Scotland, these gases are employed in a state of ignition, either alone or mixed with air, to calcine the black-band ironstone; and it is proposed that the limestone used as flux shall also be rendered caustic by the same agency. The gases are collected at about 4 or 5 feet from the mouth of the furnace, and conveyed by a horizontal pipe to the kilns situated on a rising ground immediately behind. The use of these gases has been found in no way prejudicial to the regular working of the furnaces, and in calcining ironstone alone it is said to reduce the cost of pig-iron 2*s.* 6*d.* per ton, in coal, dross and wages together.

In some of the Welsh furnaces it has been found useful to close, or partially close the tops of the furnaces, for drawing off the gases more completely. Although the closing of the furnace has sometimes been found to interfere with the working, the plan has been adopted at the Ebbw Vale and other works, without injury to the iron process. An inverted truncated cone *A* is suspended, as shown in Fig. 86, from the top of the furnace, the bottom truncated end being closed at will by a second cone *B*, the apex of which rises through the centre of the upper cone, and is attached to a central chain with an adjusting lever. When the lower cone is elevated, the gaseous escape is shut off, so that the current can only pass through the flue *c*. The furnace is fed by lowering the inner cone, when a fresh charge of fuel, &c., previously placed in the upper cone is delivered towards the sides of the furnace.

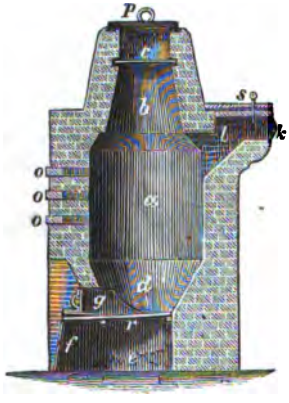
Generators.—Special furnaces for generating gaseous combustibles are employed in certain localities where there is an abundance of otherwise valueless fuel, such as wood-shavings or sawdust, small charcoal and dust, turf, refuse lignite, and small coal or slack. These substances are heaped together in long upright furnaces *(generators)*, and the combustion is kept up with only the requisite amount of air for producing a maximum

FIG. 86.



quantity of carbonic oxide gas. When charcoal and coke are used, the gases have been shown by Ebelmen to consist only of carbonic oxide and nitrogen, the latter being derived from the air; when wood, turf, brown coal, or coal are employed, carbonic acid, hydrogen and carburetted hydrogen are likewise found in the gaseous mixture.

FIG. 87.



Generators are constructed either to work *with* or *without* a blast of air. In Fig. 87 a generator without blast is shown, as used at Mägdesprung in the Hartz. The central part or body of the furnace *a* where the gases are generated is cylindrical, 5 feet in diameter and 5½ feet high; the upper part *b* and the under part *d* are conical, the upper 4⅛ and the under 2 feet high; *r* is a conical grate, below which is an ash-pit *e*, closed by an iron slab *f*. An

aperture *g* immediately above the grate is capable of being closed by an iron door. When the damper *s* is raised the gases escape by the duct *l* into the square flue *k*, the upper part of which is constructed of iron plates, and covered with sand to retain the heat. The throat of the furnace is separated from the body by an iron damper *c*, and the top closed by an iron lid *p*. The space between *c* and *p* is just sufficient to hold one charge of combustible matter with which the generator is supplied at intervals, and by withdrawing the damper *c* while the lid is in its place, the charge can be introduced without any escape of gas through the throat.

In working the generator, a layer of burning fuel, which we will assume to be charcoal, is thrown upon the grate *r*, and the whole furnace filled up to *p* with the same material. The door *g* being closed, air enters below the grate through 3 apertures, 2 inches in diameter, in the slab *f*. The carbonic acid at first produced by the ignited charcoal, on traversing the upper layers of red-hot fuel, soon becomes converted into carbonic oxide, which gas in the upper regions of the generator being only mixed with nitrogen, exerts no farther influence on the fuel. The progress of combustion is under entire control by means of the damper *s* and the 3 apertures above referred to, and can be observed through the holes *o o o*, which, when not in use, are closed by brick stoppers. The interior of the furnace, as viewed through the lowest hole, should appear in a full glow; the combustion, as viewed through the middle hole, should be less intense, and no signs of ignition should be visible on a level with the uppermost hole, for when this is not the case, there is danger of much carbonic acid being mixed with the carbonic oxide, and more fuel must be added, and the draught diminished. When turf, wood or coal are consumed in the generator the carbonic oxide and nitrogen are naturally mixed with the tar-vapours, carburetted hydrogens, and other gases produced by the dry distillation of those substances, some carbonic acid and aqueous vapour are also generated, which tend to diminish the value of the gases as combustibles.

A generator intended to work with a blast of air is shown in Fig. 88, and was erected at the Iron-works of Audincourt, under Ebelmen's directions. In its general proportions it resembles a small iron furnace, the height from the hearth *b* to the throat being about 10 feet, the widest part above the bosses being 3 feet 4 inches, the narrowest part above the hearth about 10 inches,

FIG. 88.

and the throat 13 inches. A cast-iron pipe descends from the throat about 4½ feet into the body of the furnace, and is kept constantly filled with fuel, which at Audincourt is small charcoal. A lid is only necessary when fuel in larger lumps is employed, the small pieces offering sufficient obstacle to the passage of the gases which find free passage into the space *q*, in which there is no fuel, and thence to the flue *k*. The blast is introduced at *f*. A much more abundant supply of gases can be obtained with generators of this construction than with the former, and the pressure of the blast being considerable, they can be conducted in a downward direction to the place of consumption; while, upon Bischof's plan, the hearths on which they are to be consumed require to be placed nearly on a level with the exit-tube, which is at a considerable and often most inconvenient height, so that the bottom of the generator is often obliged to be sunk below the surface of the soil. One great obstacle to a regular supply of gas is occasioned by the fusion of the ash of the combustible to the sides of the furnace, which diminishes the draught. This has been partially obviated by mixing, as at Audincourt, about 1½ parts by volume of iron-furnace slag and clay with every 100 parts of combustible, which forms, with the ash, an easily fusible compound that can be run off from the bottom of the furnace. If the charcoal is in the form of powder, a portion of this is carried over by the blast, and interferes, from obvious reasons, with the action of the gases. The condensation of the tar-vapours in the conducting tubes is also a source of annoyance, when uncharred fuel is employed. Great care is requisite in constructing these generators that no outlet be allowed for the carbonic oxide into the spaces occupied by workmen, as the effects of the gas have been found as injurious as carbonic acid; and no ingress of air, except by the blast, must be permitted, or explosive mixtures of air and gas will be formed, which may produce the most serious consequences. It has been found expedient to subdivide the current of air as much as possible, in order to prevent any uncombined oxygen finding its way through crevices in the fuel to the mixture of gases in the

upper part of the furnace; the danger from explosion is thus diminished. The gases collected from copper smelting and puddling furnaces, have not been found applicable as fuel.

Composition of Gaseous Combustibles.—All the gases hitherto employed as fuel are mixtures of combustible and incombustible gases. The ingredients of the former class are carbonic oxide, hydrogen and a little carburetted hydrogen; the latter consist of nitrogen and carbonic acid, the nitrogen being almost wholly derived from atmospheric air. The gases vary in composition according to the part of the furnace whence they are taken: those taken immediately above the tuyeres, where the consumption of the fuel is complete, consist principally of carbonic acid, nitrogen and some hydrogen, the latter being derived from the decomposition of the aqueous vapour of the air in contact with the red-hot charcoal. As this mixture ascends through other layers of red-hot charcoal or coke, the carbonic acid becomes converted into carbonic oxide, and higher still in the furnace, a reconversion of a portion of carbonic oxide into carbonic acid is effected by the reduction of the oxides of iron, which then mingles with the other products from the dry distillation of the fuel, and near the throat a large quantity of aqueous vapour forms part of the mixture. The temperature and pressure of the blast likewise exert influence upon the composition of the gaseous mixture.

Bunsen was the first to examine the composition of the gases from the iron-furnace, and those which formed the subject of his experiments were taken from the furnace of Veckerhagen in Hesse, in which wood charcoal was consumed as fuel. The following table exhibits their composition at different elevations above the tuyeres.

Height above the tuyeres at which the gases were collected.	Composition of furnace gases in 100 volumes.						
	5½ ft.	8½ ft.	11½ ft.	13½ ft.	14½ ft.	16½ ft.	17½ ft.
Nitrogen	64.58	61.45	63.89	62.47	66.29	62.25	62.34
Carbonic acid	5.97	7.57	3.60	3.44	3.32	11.14	8.77
Carbonic oxide	26.51	26.99	29.27	30.08	25.77	22.24	24.20
Carburetted hydrogen	1.88	3.84	1.07	2.24	4.04	3.10	3.36
Hydrogen	1.06	0.15	2.17	1.77	0.58	1.27	1.33
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Quantity of oxygen in combination for every 100 vols. of nitrogen	29.8	34.2	28.5	29.6	24·4	37.3	33.4
Quantity of carbon-vapour for every 100 vols. of nitrogen	26.6	32.9	26.6	28.6	25·0	29.3	29.1

The furnace at Veckerhagen was 20¾ ft. high from the tuyeres to the mouth. The temperature of the blast during the time of collecting the gases ranged from 150° to 300° C. (300° to 572° F.), and the pressure amounted to 16 or 17 inches of water.

The gases evolved from a furnace at Clerval, in which wood charcoal was employed as fuel, were analyzed with the following results by Ebelmen.

	Composition of gases by volume.					
Height above the blast	8 ft.	9½ ft.	13½ ft.	17½ ft.	22½ ft.	furnace mouth. 25½ ft.
Nitrogen	63.07	60.54	59.14	58.15	57.80	57.79
Carbonic acid	0.00	2.23	8.86	13.76	13.96	12.88
Carbonic oxide	35.01	33.64	28.18	22.65	22.24	23.51
Hydrogen	1.92	3.59	3.82	5.44	6.00	5.82
Total	100.00	100.00	100.00	100.00	100.00	100.00
Quantity of oxygen in combination to every 100 of nitrogen	27.8	31.0	38.9	43.1	43.3	42.7
Quantity of carbon-vapour to every 100 of nitrogen	27.7	29.6	31.3	31.3	31.4	31.5
Vapour of water to every 100 vols. gas	„	0.4	0.9	2.06	13.4	11.9

The height of the furnace at Clerval from the blast to the mouth was 25½ ft. The temperature of the blast was about 180° C. (356° F.), and the mean pressure 7.57 lines of mercury.

Scheerer and Langberg's examination of the gases from the Norwegian furnace at Bärum, where wood charcoal, was also employed, gave the following results:

	Composition of gases by volume.					
Height above the blast	10 ft.	13 ft.	15½ ft.	18 ft.	20½ ft.	23 ft.
Nitrogen	64.97	66.12	64.28	63.20	62.65	64.43
Carbonic acid	5.69	8.50	4.27	12.45	18.21	22.20
Carbonic oxide	26.38	20.28	29.17	18.57	15.33	8.04
Carburetted hydrogen	0.00	1.18	1.23	1.27	1.28	3.87
Hydrogen	2.96	3.92	1.05	4.51	2.53	1.46
Total	100.00	100.00	100.00	100.00	100.00	100.00
Oxygen in combination to every 100 parts of nitrogen	29.0	28.2	29.3	34.4	41.3	40.7
Vapour of carbon to every 100 parts of nitrogen	25.7	22.7	26.9	25.5	27.8	26.5

The furnace of Bärum was 28 ft. high from the blast to the mouth. The temperature of the blast during the collection of the gases

was between 200° and 300° C. (392°—572° F.), and the pressure 14 lines of mercury.

When furnace gases are employed as fuel, it is of course desirable to withdraw them from that part of the furnace where analysis shows the largest amount of combustible ingredients. This, however, could not be done without materially interfering with the process of reduction, for which the furnaces are employed, the carbonic oxide gas being the chief, if not the sole agent in reducing the oxide of iron to the state of metal. Theory and practice have both decided that the gases cannot be withdrawn without injury to the reducing process, at a lower level than about one-third of the height from the top; so that at Veckerhagen they might be taken at about 13½ ft., at Clerval at 17½ ft., and at Bärum at about 15½ to 18 ft. above the blast. Above this level they become mixed with aqueous vapour, as was shown by Ebelmen's experiments at Clerval, which reduces their heating effect. The gases capable of being advantageously used from the three furnaces will, therefore, have the following composition by volume:

	From the furnace of:			
	Veckerhagen.	Clerval.	Bärum. (I.) 15½ ft.	Bärum. (II.) 18 ft.
Nitrogen	62.47	58.15	64.28	63.20
Carbonic acid . .	3.44	13.76	4.27	12.45
Carbonic oxide . .	30.08	22.65	29.17	18.57
Carburetted hydrogen	2.24	0.00	1.23	1.27
Hydrogen	1.77	5.44	1.05	4.51
	100.00	100.00	100.00	100.00

The composition of the gases from Veckerhagen and those from Bärum (I.), and those from Clerval and Bärum (II.), are so nearly the same, that a mean may be taken in afterwards calculating their relative values. Their mean composition by volume will be expressed as follows:

	A. Veckerhagen and Bärum (I.) mean.	B. Clerval and Bärum (II.) mean.
Nitrogen	63.4	60.7
Carbonic acid . . .	3.9	13.1
Carbonic oxide . .	29.6	20.6
Carburetted hydrogen	1.7	0.6
Hydrogen	1.4	5.0
	100.00	100.00

This composition by volume corresponds to the following composition by weight:

	A.	B.
Nitrogen	63.4	59.7
Carbonic acid	5.9	19.4
Carbonic oxide	29.6	20.2
Carburetted hydrogen	1.0	0.3
Hydrogen	0.1	0.4
	100.00	100.00

The following results were obtained by Ebelmen, as the composition of the gases from the furnaces of Vienne and Pont l'Eveque, which are worked with coke as fuel.

	Composition of the gases from the furnace of Vienne.			
Height above the blast	2 ft.	17½ ft.	28 ft.	31½ ft.
Nitrogen	61.07	64.66	63.59	60.70
Carbonic acid	0.68	0.57	2.77	11.58
Carbonic oxide	36.84	33.39	31.83	25.24
Hydrogen	1.41	1.38	1.81	2.48
Total	100.00	100.00	100.00	100.00
Vapour of water to every 100 parts of dry gas	„	„	„	5.9
Vapour of carbon to every 100 vols. of nitrogen	30.7	26.4	27.2	30.3
Excess of oxygen over that contained in atmospheric air to every 100 parts of nitrogen	5.0	0.6	3.1	13.6
Amount of hydrogen to every 100 parts of nitrogen	2.3	2.1	2.8	4.1

	Composition of gases from the furnace of Pont l'Eveque.					
Height above the blast	⅝ ft.	1 ft.	2 ft.	10½ ft.	22½ ft.	33½ ft.
Nitrogen	75.10	71.20	62.70	64.47	62.72	62.47
Carbonic acid	8.11	5.87	0.16	0.17	0.68	7.15
Carbonic oxide	16.53	22.25	36.15	34.01	35.12	28.37
Hydrogen	0.26	0.68	0.99	1.35	1.48	2.01
Total	100.00	100.00	100.00	100.00	100.00	100.00
Vapour of carbon to every 100 of nitrogen	16.4	19.7	28.9	26.5	28.5	28.4
Excess of oxygen over that contained in atmospheric air for every 100 parts of nitrogen	4.4	2.4	2.8	0.7	2.8	7.9
Hydrogen to every 100 parts of nitrogen	0.3	0.9	1.6	2.1	2.4	3.2

The height of the Vienne furnace from the blast to the mouth was 31¼ ft., the temperature of the blast 220°—250° C. (428°—

482° F.), and the pressure 0.04 millgrs. of mercury. The height of the furnace at Pont l'Eveque from the blast to the mouth is 33½ ft., the temperature of the blast 130° C. (266° F.), and the pressure 0.026—0.030 mill. of mercury. The parts of the furnaces from which the gases should be taken are respectively 20 ft. above the blast in the former, and 22 ft. in the latter. As no gases from that part were examined in the Vienne furnace, those taken at 17½ ft. above the blast may be compared with the gases from Pont l'Eveque, a mean being taken between the two.

	Vienne.	Pont l'Eveque.	Mean.
Nitrogen	64.66	62.72	63.7
Carbonic acid . . .	0.57	0.68	0.6
Carbonic oxide . . .	33.39	35.12	34.3
Hydrogen	1.38	1.48	1.4
	100.00	100.00	100.00

This composition by volume corresponds with the following by weight:

Nitrogen	64.4
Carbonic acid . . .	0.9
Carbonic oxide . .	34.6
Hydrogen	0.1
	100.00

Ebelmen has since made experiments at the furnace of Seraing, and corroborated the previous general results, the only difference consisting in a small quantity of carburetted hydrogen, which was not estimated by the method of analysis adopted at Vienne and Pont l'Eveque. The analysis of these gases was performed by the eudiometric process, while the former were analyzed by combustion with oxide of copper and direct weighing.

	Composition of gas by volume from furnace of Seraing.							
Height above the blast . .	1 ft.	34 ft.	36 ft.		37 ft.	42 ft.	45 ft.	
			I.	II.			I.	II.
Nitrogen	54.63	61.34	61.67	61.15	62.46	59.69	57.06	56.64
Carbonic acid . . .	„	0.10	1.08	1.13	1.54	9.85	11.39	11.39
Carbonic oxide . .	45.05	36.30	35.20	35.35	33.88	28.06	28.61	28.93
Carburetted hydrogen	0.07	0.25	0.33	0.29	1.43	1.48	0.20	„
Hydrogen	0.25	2.01	1.72	2.08	0.69	0.97	2.74	3.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oxygen for every 100 vols. of nitrogen .	41.2	29.9	30.2	30.6	29.6	40.0	45.0	45.6
Vapour of carbon for every 100 vols. of nitrogen	41.3	29.9	29.6	30.0	29.4	33.0	35.2	35.7

The height of the furnace of Seraing from the blast to the mouth was 46 ft. The blast was heated to 212° F., and the pressure was 0.05 mill. of mercury. It will be observed that at the corresponding height above the blast, or at 34 to 36 ft. in this furnace, as compared with the other two, the gases have very nearly the same composition.

The gases from iron-furnaces consuming coal as fuel have been examined at Alfreton, Derbyshire, by Bunsen and Playfair, at nine different levels. Their results were as follows:

Height above the blast	2¼ ft.	12 ft.	13¾ ft.	16¾ ft.	19¾ ft.	22¾ ft.	25¾ ft.	28¾ ft.	31¾ ft.
Nitrogen . .	58.05	56.75	58.28	60.46	55.49	50.95	52.57	54.77	55.35
Carbonic acid	—	10.08	8.19	10.83	12.43	9.10	9.41	9.42	7.77
Carbonic oxide	37.43	25.19	26.97	19.48	18.77	19.32	23.16	20.24	25.97
Light carburetted hydrogen	—	2.33	1.64	4.40	4.31	6.64	4.58	8.23	3.75
Hydrogen . .	3.18	5.65	4.92	4.83	7.62	12.42	9.33	6.49	6.73
Olefiant gas .	—	—	—	—	1.38	1.57	0.95	0.85	0.43
Cyanogen . .	1.34	trace	trace	—	—	—	—	—	—
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The height of the Alfreton furnace from the blast to the mouth was 36¾ ft. The blast was heated to 626° F., with a pressure of 6.75 inches of mercury.

The most appropriate spot for withdrawing the gases from this furnace would be at about 22¾ ft. above the blast, where the gases have the following composition:

Nitrogen	50.95
Carbonic acid	9.10
Carbonic oxide	19.32
Light carburetted hydrogen	6.64
Hydrogen	12.42
Olefiant gas	1.57
	100.00

The composition by weight corresponding to the above is as follows:

Nitrogen	56.3
Carbonic acid	15.2
Carbonic oxide	21.5
Light carburetted hydrogen	4.2
Hydrogen	1.0
Olefiant gas	1.8
	100.00

The gases evolved from the anthracite furnaces at Ystalyfera were analyzed at two levels by Schafhautel, with the following results:

Depth below the coal and mineral . .	16 ft.	1 ft.
Nitrogen	49.844	54.505
Carbonic acid	00.136	9.546
Carbonic oxide	18.974	12.012
Light carburetted hydrogen . .	3.212	2.548
Hydrogen	27.844	21.278
Sulphurous acid, with traces of arsenicated and phosphuretted hydrogen	trace	0.111
	100.000	100.000

Composition of Gas from Generators.—The gases from generators, being prepared with a special view to their application as fuel, do not vary so much in composition as those from furnaces which can only be withdrawn so as not to interfere with the smelting process.

The following is the composition of generator gases:

GENERATOR GASES FROM WOOD CHARCOAL.

	I.	II.	III.	Mean composition: By volume.	By weight.
Nitrogen . . .	63.37	62.38	64.47	63.41	64.9
Carbonic acid . .	0.45	0.59	0.50	0.51	0.8
Carbonic oxide .	33.63	32.74	33.51	33.29	34.1
Hydrogen . . .	2.55	4.29	1.52	2.79	0.2
	100.00	100.00	100.00	100.00	100.00

GENERATOR GASES FROM WOOD.

FIRST KIND.

	I.	II.	III.	Mean composition of II. & III.: By volume.	By weight.
Nitrogen . . .	51.54	50.72	49.48	50.11	53.2
Carbonic acid . .	9.55	6.67	7.80	7.23	11.6
Carbonic oxide .	29.45	32.21	32.59	32.40	34.5
Hydrogen . . .	9.46	10.39	10.13	10.26	0.7
	100.00	100.00	10.00	100.00	100.00

SECOND KIND.

	I.	II.	III.	Mean composition: By volume.	By weight.
Nitrogen . . .	51.34	49.14	49.64	49.97	55.5
Carbonic acid . .	12.70	13.43	13.27	13.20	22.0
Carbonic oxide .	18.86	18.60	19.48	18.98	21.2
Hydrogen . . .	17.10	18.83	17.61	17.85	1.3
	100.00	100.00	100.00	100.00	100.00

GENERATOR GASES FROM TURF OR PEAT.

	I.	II.	Mean composition: By volume.	By weight.
Nitrogen . . .	64.13	58.81	61.47	63.1
Carbonic acid .	7.32	10.79	9.06	14.0
Carbonic oxide .	22.63	21.04	21.83	22.4
Hydrogen . .	5.92	9.36	7.64	0.5
	100.00	100.00	100.00	100.00

GENERATOR GASES FROM COKE.

	I.	II.	Mean composition: By volume.	By weight.
Nitrogen . . .	64.64	63.63	64.14	64.8
Carbonic acid .	0.80	0.91	0.85	1.3
Carbonic oxide .	33.31	33.76	33.53	33.8
Hydrogen . .	1.25	1.70	1.48	0.1
	100.00	100.00	100.00	100.00

The apparent absence of all carburetted hydrogen in these mixtures of gases, is due to the method of analysis adopted by Ebelmen; these ingredients would probably only enter in small proportion into the mixture, and the above numbers may therefore be employed for all practical purposes in calculating their relative heating values.

RELATIVE VALUE OF FUEL.

Different kinds of fuel are by no means capable of producing a like amount of heat, and it becomes both interesting and highly important to learn the methods which science has adopted for ascertaining their maximum heating effect. The results obtained from these researches are called the *theoretical calorific effect;* and in order to ascertain this, it is necessary to know the *quantity of heat* which a certain amount of fuel is capable of producing, and the *time* which is required for effecting that object. These two points furnish the idea of what is called *heating power*. The *value of the fuel* depends upon its *heating power*, and its *price* at the time of consumption; it varies, therefore, in different localities, and can only be relatively fixed.

Strictly speaking, the determination of the first point (the quantity of heat) is impossible, as heat cannot be weighed or measured; the quantity of heat, therefore, which a body produces during com-

bustion, cannot *itself* be ascertained; but for practical purposes a knowledge of the *absolute* quantity is not required, it is sufficient to know how much the quantity of heat produced by one kind of fuel exceeds or falls short of that produced by another, the actual quantities produced by each being undetermined. Several methods have been employed at different times to ascertain this relative heating power. The more ancient, purely physical experiments, undertaken by the most distinguished men of science, were all conducted upon the same principle, that of causing the whole quantity of heat (actually unknown) which a burning substance or fuel emits, to act upon a third body, in order to compare the action which the different kinds respectively had upon it. The apparatus by which this was done, is the well-known *calorimeter*. Lavoisier and Laplace caused the heat evolved in this apparatus to act upon ice, and measured the amount of heat by the quantity of ice that was melted. At a later period, Count Rumford, to whom we are indebted for many experiments upon fuel, used water instead of ice, and measured the quantity of heat by the increase of temperature produced in a given quantity of water. Both methods of determination are in fact the same, the quantity of heat which will melt 1 lb. of ice at 0°, being just sufficient, according to Lavoisier and Laplace, to raise the temperature of as much water (1 lb.) 75° C.; or what is the same thing, to raise 0.75 lb. of water 100° C.* Clement and Desormes have likewise shown, that an equal weight of aqueous vapour, whatever may be its temperature and tension, is always produced by one and the same amount of heat, and consequently always contains that same quantity; and, farther, the quantity of heat which water at 100° C. absorbs (latent heat) in a manner no longer indicated by the thermometer, in order to be converted into vapour, is 5.5 times (according to Rumford, 5.67) sufficient to heat the same weight of water from 0° to 100° C. it is therefore easy to calculate how much water would be converted into vapour by the heat that is required to melt 1 lb. of ice.

Rumford's experiments, which only extended to the different kinds of wood, led to the following results:

* This number was obtained as the mean of two determinations, which were 73 and 76. From the more recent and accurate experiments of de la Prevostaye and Desains as well as from those of Regnault, it appears that this number must be raised to 79.

One pound of the following kinds of wood, when burnt, will heat:	Pounds of water from ° to 100° C.
1. Lime-tree.	
Dry wood, 4 years old . .	34.707
„ „ slightly dried .	38.833
„ „ strongly dried .	40.131
2. Beech.	
Dry wood, 4 or 5 years old .	33.798
„ „ strongly dried .	36.746
3. Elm.	
Wood, rather damp . . .	32.147
„ dried, 4 or 5 years old	30.205
„ strongly dried . . .	34.083
„ dried brown . . .	30.900
4. Oak.	
Common firewood, in small shavings	26.272
The same in thicker shavings	25.590
„ thick shavings .	24.478
„ dried in the air .	29.210
Very dry wood in thin shavings	29.838
„ „ thicker „	26.227
5. Ash.	
Common dry wood . . .	30.666
The same dried in air, shavings	33.720
The same, shavings dried in an oven	35.449
6. Sycamore.	
Strongly dried in an oven .	36.117
7. Mountain ash.	
Strongly dried in an oven .	36.130
Dried brown	32.337
8. Bird cherry.	
Dried wood	33.339
Strongly dried in an oven .	36.904
Dried brown	34.736
9. Fir (deal).	
Ordinary dry wood . . .	30.322
Well dried in the air, in shavings	34.000
Well dried in an oven, in shavings	37.379
Well dried brown, in shavings	33.358
Well dried, in thick shavings	28.695
10. Poplar.	
Wood dried in the ordinary manner	34.601
Wood strongly dried in an oven	37.161
11. Hornbeam.	
Dried wood (ordinary) . .	31.704

By means of instruments of the same kind, the following results have also been obtained:

1 lb. of hydrogen	will raise the temperature of	236	lbs. of water			from 0° to 100° C.
1 „ pure carbon	„	„	78	„	„	
1 „ wood charcoal	„	„	75	„	„	
1 „ dry wood	„	„	36	„	„	
1 „ wood containing 20 per cent of water	„	„	27	„	„	
1 „ good coal	„	„	60	„	„	
1 „ peat	„	„	25—30	„	„	
1 „ alcohol	„	„	67	„	„	
1 „ ether	„	„	80	„	„	
1 „ vegetable oil, rape oil, wax oil, &c.	„	„	95	„	„	

The same quantity of heat being required to raise the temperature of 100 lbs. of water 1° as in heating 1 lb. of water 100°, it follows from the above results, that

1 lb. of hydrogen	will raise the temperature of	23,600	lbs. of water	1° C.
1 „ vegetable oil, rape-oil, wax, &c.	„	„	9,000—9,500	„	„	
1 „ ether	„	„	8,000	„	„	
1 „ pure charcoal	„	„	7,800	„	„	
1 „ wood charcoal	„	„	7,500	„	„	
1 „ alcohol	„	„	6,700	„	„	
1 „ good coal	„	„	6,000	„	„	
1 „ dry wood	„	„	3,600	„	„	
1 „ wood containing 20 per cent moisture	„	„	2,700	„	„	
1 „ peat	„	„	2,500—3,000	„	„	

The numbers placed against the different combustibles in this table, or the quantities of water which 1 part of a combustible will raise 1° of C. in temperature, represent units of heating power—the quantity of heat necessary to raise a given quantity (1 lb.) of water 1° C. being assumed as unity or the standard of comparison for the effects of heat.

If the heating effect of pure carbon be taken as unity, the relative heating values of the other combustibles will range as follows:

Hydrogen	8.03
Vegetable oil, &c.	1.15—1.22
Ether	1.02
Carbon	1.00
Wood charcoal	0.96
Alcohol	0.86
Good coal	0.77
Dry wood	0.46
Wood with 20 per cent water	0.35
Peat	0.33—0.38

It appears from this table that the absolute heating effect of hydrogen is very nearly 3 times as great as that of carbon, and making allowance for the necessary slight inaccuracy of all experimental results, it may be assumed as exactly 3 times that of carbon.

The greater the quantity of hydrogen, therefore, contained in any combustible body, the greater will be its heating effect.

A most remarkable connection between the quantities of heat evolved, and the chemical process of combustion, was first pointed out by Welter in the calorimetrical experiments of Laplace, Lavoisier, Despretz, Rumford, and others, and gave rise to a new and more convenient method of determining the heating power. Welter observed that those quantities of a combustible body

which require an equal amount of oxygen for combustion, evolve also equal quantities of heat, as is shown by the following examples:

1 lb. of:	will heat lbs. of water from 0° to 100° C.	Or, 1 lb. of oxygen in consuming:	will heat lbs. of water from 0° to 100° C.
Hydrogen . . .	236.4 Despretz	0.125 lb.	2.955
Charcoal . . .	78.15 „	0.375 „	2.931
Perfectly dry wood	43.141 Rumford	0.724 „	3.093

In the greater number of combustible bodies, the differences observed were not greater than might have been anticipated from the difficulties attending all calorimetrical researches, whilst in others, as phosphorus, iron, &c., they were twice as great. Welter therefore drew the conclusion, that the oxygen required for the combustion of a body being in the same relation as the quantity of heat evolved, might fairly be made the measure of the heating power. In fact, we are led, *a priori*, to this supposition, if we consider that, on the one hand, the heat evolved must bear some relation to the mass of the body burnt; and, on the other, that oxygen may with equal propriety be considered the combustible, as the body with which it combines (the fuel). When, therefore, oxygen burns by means of carbon, wood, hydrogen, &c., the heat which is evolved must increase with the quantity of it that is consumed; or the same amount of heat is generated by a certain given weight of oxygen, whether that quantity be employed in converting carbon into carbonic acid, or hydrogen into water. The amount of heat generated can easily be calculated from the experimental results given at p. 172. For as

1 part of carbon requires for combustion $2\frac{2}{3}$ parts of oxygen, and
1 „ hydrogen „ „ 8 „ „

and

1 part of carbon will raise the temperature of 78 parts of water, and
1 „ hydrogen „ „ 236.4 „ „

from the freezing to the boiling point, it follows directly that

1 part of oxygen in burning carbon will heat $\frac{78}{2\frac{2}{3}} = 29.25$ parts of water,

1 part of oxygen in burning hydrogen will heat $\frac{236.4}{8} = 29.56$ „ „

from the freezing to the boiling point.

In round numbers, therefore, the heating effect of oxygen may be assumed at 30 or expressed in units of heating power at 3000.

Absolute Heating Effect.—If, therefore, the quantity of oxygen required by 1 part of a combustible be denoted by O, the absolute heating power of that combustible may be expressed by the equation

$$(1) \qquad A = 3000\, O$$

or $A = 3000 \frac{n}{\alpha}$, in which latter formula, n = the number of oxygen atoms with which the body combines during combustion, and α = the atomic weight of the substance, that of oxygen being = 1.

The number obtained by means of either of these equations consequently indicates the amount of water which will be raised 1° C. in temperature by the heat generated during the combustion of 1 part of the combustible body.

The formula may easily be extended for bodies containing more than one combustible element. Let a fuel contain $a\ b\ c\ d$ parts by weight of different combustible ingredients, which respectively combine with $O\ O'\ O''\ O'''$, parts by weight of oxygen, then

$$(2) \qquad A = 3000\,[a\,O + b\,O' + c\,O'' + \ldots.]$$

$$\text{or } A = 3000 \left[a\frac{n}{\alpha} + b\frac{n'}{\beta} + c\frac{n''}{\gamma} + \ldots. \right] \qquad (4)$$

In the latter formula $n\ n'\ n''\ \ldots$ denote the number of oxygen atoms with which 1 part of the corresponding combustible bodies combine; $\alpha\ \beta\ \gamma\ \ldots$ denote the equivalent weights of those bodies.

The second formula is deduced from the first by making

$$O = \frac{n}{\alpha},\ O' = \frac{n'}{\beta},\ O'' = \frac{n''}{\gamma} \ldots$$

The absolute correctness of Welter's theory has not been proved, indeed recent researches (as will be stated presently) tend to invalidate it; but Berthier has founded a practical process upon it, to determine in one experiment the quantity of oxygen requisite for combustion, and thus the heating power of the combustible. It consists in mixing intimately a weighed quantity (10 grs.) of the combustible with a large excess (400 grs.) of pure litharge (protoxide of lead). The mixture is placed in a crucible, sufficiently capacious to contain 3 times the bulk of the mixture, and rendered impervious to the gases of the furnace by a coating of fire-clay or by a glaze, and is covered with an equal

quantity of pure litharge. The crucible being covered with a lid and placed on a support in a furnace, is slowly heated to redness, and when the gases which cause the mixture to swell considerably have escaped, the crucible is covered with fuel, and strongly heated for about ten minutes in order to collect the globules of reduced lead into a single button at the bottom of the mass of fused litharge. The oxygen of the oxide of lead combines with and burns the combustible ingredients of the fuel, leaving for every equivalent of oxygen consumed an equivalent of reduced metallic lead. It is, therefore, only necessary to weigh the metallic lead, which is easily separated from the fused litharge by a few strokes of the hammer, in order to discover the amount of oxygen consumed and the relative heating power of the fuel. If, however, it is required to ascertain the quantity of water heated up to 1° or 100° C., it is necessary to refer to the known calorimetric power of a single combustible body, and carbon is then usually made the standard of comparison. Now 1 part of pure carbon requires 2.666 parts of oxygen, which taken from litharge, leave 34.5 parts of metallic lead; the same quantity of carbon, according to Despretz, is sufficient to heat 78.15 parts of water from 0° to 100°; so that every unit of lead that is reduced by any kind of fuel, corresponds to $\frac{78.15}{34.5}=2.265$ parts of water, which it can raise from 0° to 100° C.*

An elementary analysis, in which the substance is completely consumed—its carbon being converted into carbonic acid and its hydrogen into water—affords a means of calculating with greater accuracy its heating power, compared with that of carbon as unity.

If H is made to denote the percentage amount of hydrogen, and C the percentage amount of carbon, in any kind of fuel containing only carbon and hydrogen, the heating power of hydrogen being 3 times that of carbon, the absolute heating effect A of the fuel will be expressed by the formula:

$$A=3H+C. \qquad (3).$$

But if, at the same time, with carbon and hydrogen, the fuel also contain oxygen, and this is already in combination with either

* Practical experiments upon a large scale, as well as elementary analysis, have shown that the determinations made with litharge are liable to a constant error, and afford results which are always about $\frac{1}{4}$ below the actual calorific power.

carbon or hydrogen, it of course must diminish the absolute heating power of the fuel, and as 1 equiv. of carbon takes up 2.666, and 1 equiv. of hydrogen takes treble that quantity—namely, 8 parts of oxygen—we have to deduct from the sum of both, the quantity of oxygen actually present in the combustible—*i. e.*, supposing it is known to be already in combination—in order to ascertain the quantity furnished from without, which then becomes the measure of the heating power; *e. g.*, in oak-wood there are: 0.4943 parts carbon, and 0.0607 hydrogen, which would give

$$0.4943 \times 2.666 + 0.0607 \times 8 = 1.318 + 0.485 = 1.803.$$

If the oxygen in the oak-wood, viz. 0.445, is deducted from that quantity, we obtain $1.803 - 0.445 = 1.358$ as the amount of oxygen required, corresponding to 17.58 of lead reduced, or to 39.8 of water, which would be heated to 100° C. by 1 part of oak-wood. Or, as 1 part of oxygen is combined in carbonic acid with $\frac{3}{8}$ parts of carbon and in water with $\frac{1}{8}$ of hydrogen, and we designate by O the quantity of oxygen contained in the combustible, its absolute heating effect A will be expressed by one or other of the following formulæ, according as the oxygen is supposed to detract from the heating effects of the carbon or hydrogen:

$$A = 3\,H + C - \tfrac{3}{8}\,O$$

or

$$A = 3\,[H - \tfrac{1}{8}\,O] + C. \qquad (4)$$

To convert the product from either of these equations into units of heating power, it is only necessary to multiply by the heating power of carbon = 7800.

As an example, the heating power of alcohol may be thus calculated. The elementary composition of alcohol is expressed by the formula:

$$C_4\,H_5\,O + H\,O,$$

and it contains in 100 parts:

Carbon . .	52.66
Hydrogen . .	12.90
Oxygen . .	34.44
	100.00

The one half of the oxygen in alcohol, according to the formula,

is already combined with hydrogen to form water. The heating power of alcohol will consequently be=

$$3\,(0.129-\tfrac{1}{8}\,.\,\tfrac{1}{2}\,.\,0.3444)+0.5266=0.85,$$

which agrees very closely with the experimental number of the table at p. 173.

Specific Heating Power.—The specific heating power of a combustible is expressed by the amount of heat which a certain volume of the combustible yields during perfect combustion. The absolute heating power being ascertained, it is only necessary to multiply that by the specific gravity of the combustible in order to obtain its specific heating power.

The following table exhibits the specific heating power of the combustible bodies enumerated in the tables (p. 173), the specific heating power of pure carbon (diamond) being=100.

Pure carbon (diamond) . . .	100
Good coal	33.00
Vegetable oil	30.20
Ether	21.10
Alcohol	19.80
Dry wood	5.26
Wood charcoal	4.94
Wood containing 20 per cent moisture.	4.91
Hydrogen	0.0077

The specific gravities from which the numbers in the above table have been deduced are the following: Diamond=3.5, coal=1.5, vegetable oil=0.92, ether=0.72, alcohol=0.8, dry wood=0.4, wood with 20 per cent moisture=0.5, wood charcoal =0.18, hydrogen (compared with water)=0.00009.

For the specific gravity of porous substances, such as wood and wood charcoal, numbers have been taken which have reference to those substances in the usual state when their pores are filled with air.

Pyrometrical Heating Effect.—The pyrometrical heating effect of a combustible is expressed by the degree of heat evolved during its complete combustion. Various instruments have been constructed for the approximative estimation, in a direct manner, of the high degrees of temperature which most ordinary combustibles produce during combustion; but none of these instruments, which are

called *pyrometers*, have attained such a degree of perfection as to admit of perfect reliance being placed upon their indications.

Wedgwood adapted the progressive contractility of clays at very elevated temperatures to the construction of the pyrometer which bears his name. The instrument consists of a plate of copper, upon which two strips of the same metal gradually converge to one point, between which small truncated cones of clay are inserted, these latter passing farther forward towards the point at which the two strips meet in proportion to the contraction which the clay has undergone by exposure to different high degrees of temperature. Great care is required in the preparation of the clay for these small cones; it should always be of the same composition, and, containing an equal amount of water, should be baked at the same temperature. The diminution of volume which clay sustains at higher temperatures is partly due to a loss of water, and partly to a closer agglomeration of the particles in obedience to some law yet unknown. Incipient redness has been adopted for the zero point on Wedgwood's scale, and is the point at which the cones, having been heated to that temperature, are arrested by the strips of metal. 240 divisions are traced upon one of the strips beyond that point, each one of which corresponds to 72° of the centigrade thermometer (130° F.) In order to ascertain the temperature of a furnace by this pyrometer, one of the small clay cones is placed in a crucible, in which it is allowed to acquire the temperature of the furnace; it is then withdrawn, and having been allowed to cool, is inserted between the two metallic strips; the point at which its farther progress is arrested then indicates the temperature to which it has been exposed. The difficulty of securing at all times the same quality of clay, and consequently the same contraction for the same temperature, render this pyrometer next to useless; indeed it is now no longer in use in the Staffordshire potteries, where alone, at one time, it was extensively employed.

The constant temperature at which certain metals and alloys enter into fusion may be employed to a limited extent for estimating high temperatures. M. Princep employs 10 alloys of gold and silver, containing each an increase of $\frac{1}{10}$ of gold; and 100 alloys of gold with platinum, in which the latter metal is progressively increased by $\frac{1}{100}$th. By placing a number of these alloys in pieces of the size of a pin's head upon a cupel of bone-ash in which small cavities for the reception of each alloy have been made, and introducing this into any furnace, the temperature of

which is to be determined, the alloy at which fusion has been arrested may be observed when the cupel is withdrawn. The temperature of two furnaces can thus be directly compared; but in order to arrive at a knowledge of the exact temperature of any, it is obviously necessary to ascertain the precise thermometrical degree at which each alloy enters into fusion. This has been done by M. Princep for the points of fusion of silver and several of the alloys of gold, by measuring the dilatation of air confined in a vessel of pure gold. The results of his experiments upon these points are the following:

Red heat	649° C.	(1200° F.)
Orange heat	899 „	(1650 „)
Silver fuses	999 „	(1830 „)
Silver with $\frac{1}{10}$ gold . . .	1648 „	(2998 „)
Silver with $\frac{1}{4}$ gold . . .	1121 „	(2050 „)

Daniell proposed the linear expansion of platinum as a pyrometrical standard, and the mode of applying his instrument to the measurement of furnace temperatures is familiar to every student of the elements of natural philosophy.

None of the instruments or methods proposed above for the direct estimation of high degrees of temperature have however yet become of real practical value, and we are consequently referred to the elementary composition of the combustibles, in order to estimate their pyrometrical heating values approximatively by calculation.

The entire amount of heat developed during the combustion of a combustible must necessarily be transferred to the products of combustion. The absolute heating power of the different combustibles has been expressed above by the amount of heat which they respectively communicate to a given amount of water; if this known amount of heat be transferred from water to the products of combustion, we must obviously obtain the mean temperature of the combustion, or the pyrometrical value of the fuel consumed. The specific heat of water, in reference to that of the gases generated, forming an important element in the calculation.

The following example, in which it is proposed to estimate the pyrometrical heating power of carbon by calculation will illustrate this method, and in order to complicate the calculation as little as possible, the combustion is assumed to take place in pure oxygen gas.

Carbon requires $2\frac{2}{3}$ times its weight of oxygen for complete conversion into carbonic acid. The absolute heating power is consequently according to formula (p. 175) $3000.2\frac{2}{3}=8000$. The heat generated during the combustion of 1 part of carbon will, therefore, raise the temperature of 8000 parts of water 1° of the centrigrade thermometer, or will heat 1 part of water from 0° to 8000° C., or will raise $3\frac{2}{3}$ parts of water from 0° C. to $\frac{8000}{3\frac{2}{3}}=2182°$ C. During the combustion of 1 part of carbon $3\frac{2}{3}$ parts of carbonic acid are produced, to which the entire amount of heat generated during the combustion is transferred. If, therefore, the specific heat of carbonic acid were identical with that of water, the temperature of the gas would be 2182° C.; but the specific heat of carbonic acid as compared with water as unity is=0.2210; the temperature of the carbonic acid produced by the combustion will consequently be in the inverse ratio, or $\frac{2182}{0.2210}=9873°$ C. The pyrometrical heating power of carbon burning in oxygen gas is therefore 9873° C. A general formula may be constructed in a similar manner for the pyrometrical heating power of any combustible. If O represent the amount of oxygen with which 1 part of a combustible combines on burning and s the specific heat of the products of combustion, its pyrometrical heating power will be expressed by

$$(5) \qquad P=3000.\frac{O}{(1+O)s}$$

or $P=3000\frac{n}{(\alpha+n)s}$ when O is made $\frac{n}{\alpha}$ as explained at a former page.

The pyrometrical heating power of a simple combustible body is therefore expressed by its absolute heating power in unities of heat, divided by the product of the relative weight of its combustion-product and its specific heat.

This formula has reference to a simple combustible body burning in oxygen gas. In order to establish similar formulæ for compound combustible bodies, the following physical law must be known:

When A, B, C, D, represent different quantities of the same fluid, possessing temperatures corresponding to t, t', t'', t''' degrees C, the mean temperature of the mixture of all these fluids will be

$$(R) \qquad \frac{At+Bt'+Ct''+Dt'''\ldots.}{A+B+C+D};$$

if these fluids are of different chemical constitution, and consequently have different specific heats, then when s, s', s'', s''', express their corresponding capacities for heat, the mean temperature of the mixture will be expressed by

$$(R') \qquad \frac{Ast + Bs't' + Cs''t'' + Ds'''t''' + \ldots}{As + Bs' + Cs'' + Ds''' + \ldots}$$

With the aid of this formula the problem in question may be solved in the following manner:

Let the fuel consist of a, b, c, d, parts by weight of the different combustible bodies. Then retaining the mode of expression employed on a former occasion,

By the combustion of:	The product of combustion will be obtained
a	$a\,(1+O) = A$
b	$b\,(1+O') = B$
c	$c\,(1+O'') = C$
d	$d\,(1+O''') = D$

&c., &c.

The degree of temperature produced by the combustion of a, b, c, d, or the temperature of the products of combustion (A, B, C, D) are easily obtained by means of the formula (5)

By the combustion of:	Degree of temperature obtained.
a	$3000\,\frac{O}{(1+O)\,s} = t$
b	$3000\,\frac{O'}{(1+O')\,s'} = t'$
c	$3000\,\frac{O''}{(1+O'')\,s''} = t''$
d	$3000\,\frac{O'''}{(1+O''')\,s'''} = t'''$

&c., &c.

If these values for A, B, C, and D, and for t, t', t'', t''', are now inserted in the formula R', we obtain:

$$P = 3000\,\frac{aO + bO' + cO'' + dO''' + \ldots.}{a(1+O)s + b(1+O')s' + c(1+O'')s'' + d(1+O''')s''' + \ldots.} \qquad (6\,a)$$

and when O is made $= \frac{n}{\alpha}$, $O' = \frac{n'}{\beta}$, $O'' = \frac{n''}{\gamma}$ . . .

$$P=3000\frac{a\frac{n}{\alpha}+b\frac{n'}{\beta}+c\frac{n''}{\gamma}+d\frac{n'''}{\delta}+\ldots.}{a\left(1+\frac{n}{\alpha}\right)s+b\left(1+\frac{n'}{\beta}\right)s'+c\left(1+\frac{n''}{\gamma}\right)s''+d\left(1+\frac{n'''}{\delta}\right)s''''+\ldots.} \qquad (6\,b)$$

The pyrometrical heating power of a compound combustible body is therefore expressed by its absolute heating effect in units of heat divided by the sum of the relative weights of all the products of combustion of its constituents, each of these being multiplied by its corresponding specific heat.

If the combustion take place in atmospheric air instead of in oxygen gas, the effect is very much lessened, as the whole of the nitrogen in the air which accompanies the amount of oxygen consumed is necessarily mixed with the products of combustion. It therefore becomes necessary to ascertain what proportion of nitrogen is liberated for each proportion of oxygen consumed, and likewise what mean temperature will result from the mixture of that amount of nitrogen which, without any serious error we may assume to be at 0° C., with the other products of combustion.

When carbon burns in oxygen gas, the temperature of the product of combustion was calculated at 9873° C. Atmospheric air is composed in 100 parts of 23.1 oxygen to 76.9 nitrogen; to each part of oxygen there are therefore $\frac{76.9}{23.1}=3.33$ parts of nitrogen. One part of carbon consumes in burning to carbonic acid $2\frac{2}{3}$ parts of oxygen, there will consequently be $2\frac{2}{3}\,.\,3.33=8.88$ parts of nitrogen liberated when 1 part of carbon is burned, and this nitrogen will be mixed with the carbonic acid, which if alone would have acquired the temperature of 9873° C.

The specific heat of carbonic acid is=0.2210, and that of nitrogen=0.2750.

According to formula (R') the temperature must therefore be expressed by

$$\frac{3\frac{2}{3}\times 9873\times 0.2210+8.88\times 0\times 0.2754}{3\frac{2}{3}\times 0.2210+8.88\times 0.2754}=2458°\text{ C.}$$

The general formula for the pyrometrical heating power obtained in this manner will therefore be expressed by:

$$P=3000\frac{O}{(1+O)\,s+0{\cdot}917\,O} \qquad (7)$$

or

$$P=3000\frac{n}{(\alpha+n)\,s+0{\cdot}917\,n}$$

In order to obtain a similar general formula for the combustion of a compound combustible body in atmospheric air, the following physical law must be adverted to. When $A\ B\ C\ D\ldots.$ denote different quantities of fluids, all possessing the same temperature t, but different capacities for heat $s\ s'\ s''\ s'''\ldots.$, and to these already mixed fluids a fluid Q is added, the temperature of which $=T$, and its specific heat $=\sigma$, the mean temperature of the whole will be expressed by:

$$\frac{(As+Bs'+Cs''+Ds'''+\ldots.)\,t+Q\,.\,\sigma\,.\,T}{As+Bs'+Cs''+Ds'''+\ldots.+Q\,.\,\sigma} \qquad (R')$$

The application of this formula will be readily understood. $A\ B\ C\ D\ldots.$ represent the different products of combustion of the constituents $a\ b\ c\ d\ldots$ of the fuel; $s\ s'\ s''\ s'''\ldots.$ the specific heat of the products of combustion; t is the temperature produced by the combustion of the fuel in oxygen, therefore $=P$ in the formula (6); $Q=$the quantity of nitrogen separated from the air with the oxygen consumed; $P=$the specific heat of the nitrogen, and T the original temperature of the nitrogen assumed at 0° C. There must consequently be interpolated in the formula (R'):

$$A=a\,(1+O),\ B=(1+O'),\ C=c\,(1+O'')\ldots..$$
$$s=s,\ s'=s',\ s''=s'',\ \ldots.$$
$$t=\frac{aO+bO'+cO''+\ldots.}{a\,(1+O)\,s+b\,(1+O')\,s'+c\,(1+O'')\,s''+\ldots.}$$
$$Q=3.33\,(aO+bO'+cO''+\ldots.)$$
$$\sigma=0.2754$$
$$T=O.$$

With these substitutions we obtain:

(8 *a*)

$$P=3000\,\frac{aO+bO'+cO''+dO'''+\ldots}{[a(1+O)s+b(1+O')s'+c(1+O'')s''+\ldots]+0.917[aO+bO'+cO''+\ldots]}$$

or when $O=\frac{n}{\alpha}$, $O'=\frac{n'}{\beta}$, $O''=\frac{n''}{\gamma}$, &c., &c.

(8 *b*)

$$P=3000\,\frac{a\frac{n}{\alpha}+b\frac{n'}{\beta}+c\frac{n''}{\gamma}+d\frac{n'''}{\delta}+\ldots}{\left[a\left(1+\frac{n}{\alpha}\right)s+b\left(1+\frac{n'}{\beta}\right)s'+c\left(1+\frac{n''}{\gamma}\right)s''+\ldots\right]+0.917\left[a\frac{n}{\alpha}+b\frac{n'}{\beta}+c\frac{n''}{\gamma}+\ldots\right]}$$

In these formulæ, which will be subsequently applied:

$a\ b\ c\ d\ldots$ denote the relative proportions by weight of the

different combustible bodies of which fuel is composed, the total quantity being = 1.

$O\ O'\ O''$ .... denote the relative quantities of oxygen with which those proportions combine during combustion.

$n\ n'\ n''$ .... denote the number of equivalents of oxygen with which 1 equivalent of the different combustible substances combine.

$\alpha\ \beta\ \gamma$ .... are the atomic weights of these bodies, the atomic weight of oxygen being = 1.

$s\ s'\ s''$ ... denote the specific heats of the products of combustion of the bodies consumed.

The following table contains the pyrometrical heating powers of several simple and compound bodies calculated according to these formulæ, both for combustion in pure oxygen and in atmospheric air.

	Pyrometrical heating power expressed in 0° C.	
	In oxygen.	In atmospheric air.
Carbon	9873°	2458°
Vegetable oil . . .	6024	2122
Carburetted hydrogen (CH) .	5793	2090
Ether (C_4H_5O) . . .	5484	2049
Carburetted hydrogen (CH_2) .	4800	1945
Alcohol* (C_4H_5O, HO) .	4521	1910
Hydrogen	3172	1611

Absolute accuracy has not been attempted in calculating these heating values, several more or less influential circumstances having been neglected. Amongst these may be noticed that for the coefficients $s\ s'\ s''$ those values have been introduced which have reference to the specific heats of these gases at the ordinary temperature of the air. The coefficients are consequently too small, the capacities increasing with the temperature, they should have been calculated for the temperature of combustion. As these only occur in the denominators of the formulæ, the pyrometrical heating powers will be somewhat too high. Again, the combustibles before entering into combustion all require to be heated to a certain extent. Thus, oil for instance requires a temperature of 315° C.

* In calculating the pyrometrical effect of alcohol, it has been taken into consideration that it contains 19.37 per cent of water ready formed, the evaporation of which diminishes its heating effect. The latent heat of the vapour of water has not been taken into account.

at its burning surface, at which temperature it is decomposed into gaseous products; cold oil does not burn, but the gases which are generated at a temperature of 315°, which temperature they consequently possess, and which will have a corresponding effect in raising the pyrometrical value. This cause can exert but little influence upon the calculated heating effect of ether and alcohol, as these liquids boil at such low temperatures, and none whatever upon the combustible gases hydrogen and carburetted hydrogen. In the case of carbon, however, it is the red-hot carbon alone which burns. The two former of these causes can exert but little influence on the pyrometrical value of fuel, but the latter increases to some extent the temperature of combustion of carbon and oil.

Although not absolutely accurate, the following general conclusions may be drawn from the results collated in the table above.

1. The pyrometrical heating power of carbon is greater, that of hydrogen smaller, than those of every one of the other combustibles. The combustion-temperature of carbon is more than 3 times as great as that of hydrogen. The inflammable fuels must therefore all possess a lower pyrometrical heating power than those which burn without flame, or than more or less pure carbon.

2. The pyrometrical heating power of different combustible bodies whose property of combustibility is dependent upon the carbon and hydrogen they contain, is greater, in proportion to the amount of carbon which they contain.

3. The difference between the pyrometrical heating powers of different fuels is very much more considerable when the combustion takes place in oxygen gas than when it occurs in the air. Thus between carbon and hydrogen, when burnt in oxygen gas, there is a difference of 6000° C., while in atmospheric air the difference does not exceed 800° C.

It appears anomalous that the pyrometrical heating power of carbon should be 3 times as great as that of hydrogen, while the absolute heating powers of the two substances are precisely in an opposite ratio. The cause of this lies partly in the specific heat of aqueous vapour being nearly 4 times as great as that of carbonic acid, and more especially in the circumstance that 1 part of hydrogen produces in burning 9 parts of aqueous vapour, while 1 part of carbon only affords $3\frac{2}{3}$ parts of carbonic acid.

It must also be noticed that the combustion-temperatures stated in the table above have reference to that locality either in immediate contact with the fuel or in the flame, where the actual

combustion takes place. Unfavourable circumstances may confine this to a very limited compass, and the pyrometrical effect will apparently be diminished in proportion.

In the preceding calculations, the heating power has been expressed by the quantity of water heated to 1° C. by the heat evolved during the combustion of 1 part of the combustible; but, practically, where fuel is employed for other purposes than that of raising the temperature of water, as in all metallurgical operations, the effect is very much diminished. In the apparatus employed by Rumford and others for estimating the absolute heating power, the products of combustion escape at temperatures very little above that of the water heated. The steam produced by the combustion of the hydrogen in the combustible is condensed into the state of water, &c., the large amount of heat that was latent in the steam is expended in raising the number denoting its heating power. When the combustible is employed in the furnace for producing much higher temperatures than that of boiling water, the water produced by combustion escapes in the state of steam, carrying with it its latent heat, and diminishing by so much the heating effect of the fuel. The formulæ above given will therefore require modification.

It has been proved by experiment that the quantity of heat required to evaporate 1 part of water from 100° C. is very nearly 5½ times as great as the quantity required to raise 1 part of water from 0° to 100° C. In correcting the formula for the absolute heating effect of a combustible, the total quantity of hygroscopic and chemically combined water, as well as that produced during combustion must therefore be multiplied by 5½.100=550, and the product subtracted from the previously ascertained number. If the latter be denoted by A, the corrected number by α, and the total amount of water by W, we obtain:

$$\alpha = A - 550W. \qquad (9)$$

If σ denote the corrected and S the previously calculated specific heating effect, and if π denote the corrected and P the originally calculated pyrometrical heating effect, we obtain the following proportions:

$$S : \sigma = A \text{ to } \alpha$$
$$P : \pi = A \text{ to } \alpha$$

whence

$$\sigma = \frac{\alpha}{A} S \qquad (10)$$

$$\pi - \frac{\alpha}{A} P \qquad (11)$$

In the following table (taken from Scheerer's "Metallurgie") the different heating effects of combustibles which contain water or form water during combustion, are calculated with the corrections.

In the column of absolute heating effects the heating effect of carbon is taken as unity. The numbers for the specific heating effects are the products of the absolute heating effects and the respective specific qualities of the combustibles. The pyrometrical effects are expressed in degrees of the centigrade thermometer. Dulong's determinations for the heating power of hydrogen, carbonic oxide, carburetted hydrogen, and olefiant gas have been adopted as the more correct, and the numbers obtained by Welter's law are quite inadequate to account for the effects produced in practice.

	Heating effect.		
	Absolute.	Specific.	Pyrometrical.
Wood.			
Air-dried wood (with 20 per cent hygroscopic moisture).	0.36	—	1575
Kiln-dried „ (with 10 per cent „ „)	0.41	—	1675
Kiln-dried „ (without „ „)	0.47	—	1750
White beech*	—	0.28	—
Oak	—	0.26	—
Oak	—	0.25	—
Ash	—	0.24	—
Maple, birch, bird cherry	—	0.23	—
Red beech, horse chesnut, elm, white thorn	—	0.21	—
Scotch fir, alder	—	0.20	—
Sallow	—	0.19	—
Willow	—	0.18	—
Spruce fir, silver fir, larch	—	0.17	—
Lime, aspen	—	0.16	—
Black poplar, Italian poplar	—	0.14	—
Turf.—Peat.			
Imperfectly air-dried turf (with 30 per cent. hygroscopic-water and 10 per cent of ash)	0.37	—	1575
Best air-dried turf (25 per cent moisture and no ash)	0.47	—	1750
Kiln-dried turf (no moisture and 15 per cent ash)	0.55	—	1975
Best kiln-dried turf (without moisture and ash)	0.65	—	2000
Lignite.—Brown coal.			
Air-dried, fibrous lignite (20 per cent moisture and no ash)	0.48	0.55	1800
The same (20 per cent moisture and 10 per cent ash)	0.43	—	—
Air-dried, earthy lignite (20 per cent moisture and no ash)	0.61	0.79	1975
The same (20 per cent moisture and 10 per cent ash)	0.55	—	—
Air-dried lignite, conchoidal fracture (20 per cent moisture and no ash)	0.69	0.83	2050

* The specific heating effects of all these woods are calculated from specimens in an air-dried condition.

	Heating effect.		
	Absolute.	Specific.	Pyrometrical.
Lignite.—Brown coal.			
Air-dried lignite, conchoidal fracture (20 per cent moisture and 10 per cent ash)	0.62	—	—
Kiln-dried, fibrous lignite (20 per cent moisture and no ash)	0.61	—	2025
The same (20 per cent moisture and 10 per cent ash)	0.55	—	—
Kiln-dried earthy lignite (20 per cent moisture and no ash)	0.76	—	2125
The same (20 per cent moisture and 10 per cent ash)	0.69	—	—
Kiln-dried conchoidal lignite (20 per cent moisture and no ash)	0.85	—	2200
The same (20 per cent moisture and 10 per cent ash)	0.76	—	—
Coal.			
Sand coal (5 per cent moisture and 5 per cent ash)	0.79	1.06	2200
Sinter coal (5 per cent moisture and 5 per cent ash)	0.89	0.16	2250
Caking coal (5 per cent moisture and 5 per cent ash)	0.93	1.17	2300
Anthracite (5 per cent moisture and 5 per cent ash)	0.96	1.44	2350
Wood charcoal.			
Air-dried black charcoal (12 per cent moisture and 3 per cent ash)	0.97	—	2450
Perfectly dry ditto, (3 per cent of ash)	0.84	—	2350
Air-dried red charcoal (10 p. c. moisture, 1½ per cent ash)	0.72	—	2200
Perfectly dry red charcoal	0.64	—	2100
Charcoal from Birch (No moisture and 3 per cent of ash.)	—	0.20	—
Charcoal from Ash, wild service (No moisture and 3 per cent of ash.)	—	0.19	—
Charcoal from Red beech, white beech, elm (No moisture and 3 per cent of ash.)	—	0.18	—
Charcoal from Red fir (No moisture and 3 per cent of ash.)	—	0.17	—
Charcoal from Maple (No moisture and 3 per cent of ash.)	—	0.16	—
Charcoal from Oak, pear-tree (No moisture and 3 per cent of ash.)	—	0.15	—
Charcoal from Alder (No moisture and 3 per cent of ash.)	—	0.13	—
Charcoal from Lime (No moisture and 3 per cent of ash.)	—	0.10	—
Peat charcoal.			
Worst description of air-dried peat charcoal (10 per cent moisture and 56 per cent ash)	0.85	—	2050
Best air-dried peat charcoal (10 per cent moisture, 4 per cent ash)	0.83	—	2350
Coke.			
Good coke (10 per cent moisture and 5 per cent ash)	0.84	—	2350
Best ditto (5 per cent moisture and 3 per cent ash)	0.92	—	2400
Ditto (no moisture and 3 per cent ash)	0.97	—	2450
Sand-coke (no moisture, 5 per cent ash)	—	0.46	—
Sinter-coke (no moisture, 5 per cent ash)	—	0.41	—
Caking-coke (no moisture, 5 per cent ash)	—	0.33	—
Gaseous combustibles. (Furnace gases.)			
Gases from wood charcoal A	0.108	0.000140	1675
Ditto „ „ „ B	0.080	0.000104	1450
Gases from coke	0.107	0.000139	1750
Gases from coal	0.205	0.000267	1850
(Generator gases.)			
Gases from wood charcoal	0.115	0.000150	1775
Gas from wood I	0.136	0.000177	1850
Ditto „ „ II	0.124	0.000161	1575
Gas from turf	0.092	0.000120	1525
Gas from coke	0.110	0.000143	1775

A summary view of these results is given in the following table:

	Heating effect.		
	Absolute.	Specific.	Pyrometrical.
Gaseous combustibles . . .	0.80—0.250	0.00010—0.00027	1850—1150
Wood	0.36—0.47	0.14—0.28	1575—1750
Turf	0.37—0.65	—	1575—2000
Lignite	0.43—0.85	—	1800—2200
Coal (5 per cent moisture and 5 per cent ash)	0.79—0.96	1.06—1.44	2200—2350
Peat charcoal	0.33—0.85	—	2050—2350
Wood charcoal	0.64—0.97	0.10—0.20	2100—2450
Coke (containing not above 5 per cent ash)	0.84—0.97	0.33—0.46	2350—2450

The calculations from which these numbers result have been made upon the assumption that the combustibles are entirely consumed, which certainly never occurs in practice, and the numbers must, therefore, be practically somewhat too high; they are likewise supposed to burn during a very short space of time, and give out during each successive period of that time, the same amount of heat, which we also know not to be practically the case —the process of dry distillation and the combustion of the inflammable gases always preceding the more intense heat of the glowing charcoal. Combustibles containing a large amount of ash are prevented from burning completely, by the impediment the ash offers to the draught, and to such as burn with a very smoky flame it is difficult to afford sufficient air to prevent a loss from unconsumed carbon. The effect of the gaseous combustibles is reduced below the calculated number by a certain amount of aqueous vapour, nitrogen and carbonic acid which they contain. This affects the gases evolved from wood and coal more than those from charred combustibles, and is in some measure compensated by the high temperature possessed by the combustibles before ignition.

The law of Welter has been conveniently applied to calculate the theoretical heating power of combustibles of which the composition is accurately known. Recent experiments, however, conducted with every precaution to avoid error, by Messrs. Favre and Silbermann, by Grassi, Andrews and others, have proved that the heat evolved by a given weight of oxygen is not the same when different substances enter into combination with it and are consumed.

The absolute heating power of carbon, in being converted into

carbonic acid, was found by Grassi between 7632 and 7801, by Favre and Silbermann at 8086, by Andrews at 7881, the older experimenters had fixed it at 7800; in round numbers, it may therefore still be assumed at 8000. When carbon burns to form carbonic oxide, the heating effect was estimated by Grassi at 2480.

The following are the results of different experimentalists with reference to the absolute heating effect of hydrogen.

23,640 Despretz, Lavoisier and Clement.
34,800 Dulong.
34,188 Favre and Silbermann.
34,656 Grassi.
33,808 Andrews.

The first number would indicate an amount of heat treble that afforded by carbon, and this has generally been assumed as the absolute heating effect of hydrogen. The last four results, which corroborate each other, and which have been obtained by more accurate methods, would increase the absolute heating effect of hydrogen to nearly 4½ times that of carbon, or 36,000, which may be taken in round numbers as the actual effect.

The absolute heating effects of carbonic oxide, light carburetted hydrogen and olefiant gas, have not been definitively settled even by the recent careful experiments; the results varying as follows:

Carbonic oxide.	2403—2466 Dulong, Favre and Silbermann. 2431 Andrews. 1857—1876 (sp. gr. of carb. oxide taken at 0.9678) Dalton and Grassi. 1710 according to Welter's theory.
Light carburetted hydrogen.	6375 Dalton. 13223 (sp. gr. 0.5589) Dulong. 13108 Andrews. 13158 Favre and Silbermann. 10945 Grassi. 12000 according to Welter's theory.
Olefiant gas.	6600 Dalton. 12172 (sp. gr. 0.9675) Dulong. 11942 Andrews. 11900 Favre and Silbermann. 8557 Grassi. 10290 according to Welter's theory.

When, therefore, as is probable from these results, the absolute heating power of carbon is taken in round numbers=8000, that of hydrogen=36,000 that of carbonic oxide=2404—2466 or =1857—1876, that of light carburetted hydrogen=13,158—13,223, and that of the olefiant gas=11,90—012,172, and when the quantity of heat produced by the union of 1 part of oxygen with carbon in forming carbonic acid is taken as=1, we then obtain the following relative heating powers:

1 part of oxygen produces in combining with:	Relative heating power.
Carbon	1.0
Hydrogen	1.5
Carbonic oxide . . .	1.44 or 1.1
Light carburetted hydrogen . .	1.1
Olefiant gas	1.17

These numbers, which are the coefficients of intensity, show how far the law of Welter deviates from the results of experiment. The formulæ for calculating the heating power of a combustible according to the law of Welter, will therefore require modification in order to obtain the actual effect.

The requisite alteration applies chiefly to the coefficients of intensity, and these being different for carbon and hydrogen than for carbonic oxide, carburetted hydrogen, &c., it is desirable to construct separate formulæ for the two classes of combustibles, the solid and gaseous.

FORMULÆ FOR THE ABSOLUTE HEATING EFFECT.

a. For solid fuels, containing carbon, hydrogen, nitrogen, water and ash. The heating effect of a fuel containing by weight, c parts of carbon, h of hydrogen, w water chemically combined, and w' of hygroscopic water may be calculated from the following formula, admitting that 1 part of carbon requires $2\frac{2}{3}=2.67$ parts of oxygen for complete combustion, and 1 part of hydrogen requires 8 of oxygen.

$$A=3000\,[c\,.\,2.67+1.5\,.\,h\,.\,8]-550\,[9\,.\,h+w+w'] \quad (12)$$

The above formula gives the heating power in units of heat—in order to make a comparison with that of carbon as unity, the result must be divided by 8000, the absolute heating effect of carbon. The negative element in the formula having reference to the correction for the latent heat of aqueous vapour.

b. For gaseous combustibles containing carbonic oxide, hydrogen, light carburetted hydrogen, olefiant gas, nitrogen, carbonic acid and aqueous vapour. The heating power of a fuel of this description containing by weight, k parts of carbonic oxide, h of hydrogen, g of light carburetted hydrogen, o of olefiant gas, n of nitrogen, K carbonic acid and w aqueous vapour will be obtained by means of the following formula, admitting that 1 part of carbonic oxide combines with 0.57 parts of oxygen; 1 part of hydrogen

with 8 of oxygen; 1 part of light carburetted hydrogen gas with 4 parts of oxygen; 1 part of olefiant gas with 3.43 of oxygen; and that 1 part of light carburetted hydrogen produces in burning 2.25 parts of water and 1 part of olefiant gas, 1.29 parts of water:

$$(13)\quad A=3000\,[x\,.\,k\,.\,o\,.\,57+1.5\,.\,h\,.\,8+1.1\,.\,g\,.4+ +1.17\,.\,o\,.\,3.43]-550\,[g\,.\,h+2.25\,.\,g+1.29\,.\,o\,.+w].$$

The coefficient of intensity for carbonic oxide is represented by x in the formula, as it still remains questionable whether it is 1.44 or 1.1.

The corrected formulæ for the specific heating effect are obtained from the above by multiplying the results with the respective specific gravities.

The formulæ for the pyrometric heating effect are easily deduced from those for the absolute effect, the latter being made $=A$ we obtain

a. For solid combustibles:

$$P=\frac{A}{3.67\,.\,c\,s+(g\,.\,h\,.+w+w')s'+[n+3.33\,(2.67\,.\,c\,.+8\,.\,h)]s''+a\,.\,s'''} \qquad (14)$$

In this formula s expresses the specific heat of carbonic acid, s' the specific heat of aqueous vapour, s'' the specific heat of nitrogen, and s''' the specific heat of the ash. The nitrogen which may possibly be contained in the fuel is represented by n and the ash by a.

b. For gaseous fuels, the following formula is obtained, when the absolute heating effect is $=A$, and 1 part of carbonic oxide is converted into 1.57 parts of carbonic acid; 1 part of carburetted hydrogen into 2.75 parts of carbonic acid and 2.25 of water; and 1 part of olefiant gas produces 3.14 parts of carbonic acid and 1.29 parts of water:

$$P=\frac{A}{\Sigma\,(K)\,s+\Sigma\,(w)\,s'+\Sigma\,(n)\,s''} \qquad (15)$$

$$\Sigma\,(K)=K+1.57\,.\,k+2.75\,.\,g+3.14\,.\,o$$

$$\Sigma\,(w)=w+9\,.\,h+2.25\,.\,g+1.29\,.\,o$$

$$\Sigma\,(n)=n+3.33\,(o\,.\,57\,.\,k+8\,.\,h+4\,.\,g+3.43\,.\,o).$$

The letters in the formula apply to the same magnitudes as in the previous formula for the absolute heating effect, with the exceptions of s, s' and s'', which denote respectively the capacities for heat of carbonic acid, aqueous vapour and nitrogen.

The formulæ (14) and (15) are calculated for combustion

occurring in atmospheric air; if the combustion take place in oxygen gas, the magnitude multiplied by s'' in the denominator of the fraction has only to be made $=o$ in order to obtain the corresponding heating effect.

The pyrometrical heating effects of the following substances, calculated with the aid of the above formulæ, are expressed as follows:

	Pyrometric heating effect.			
	In oxygen gas.		In atmospheric air.	
Carbon	9873° C.	(1780.3° F.)	2458° C.	(4465° F.)
Carbonic oxide. according to Dulong, Favre and Silbermann*	7090	1276.2	2828	5090
Carbonic oxide. according to Dalton and Grassi**	5316	9588.8	2121	3817
Olefiant gas	6308	1135.4	2290	4122
Light carburetted hydrogen	4766	8578.8	1935	3483
Hydrogen	4073	7334.6	2080	3744

If the determinations of Dulong, Favre and Silbermann, for the absolute heating effect of carbonic oxide are correct, the remarkable and apparently paradoxical fact would be established, that carbonic oxide burning in atmospheric air produces a greater intensity of heat than carbon itself. The circumstance is however explained, not only by the high absolute heating power of carbonic oxide, but by the lesser amount of gaseous products of combustion that result; 1 part by weight of carbonic oxide producing only 2.47 parts of gaseous products, while 1 part of carbon produces 12.57 parts when the nitrogen separated from the air is included.

The pyrometric heating effect of carbon in being converted into carbonic oxide may be calculated from the absolute heating effect of that gas, as estimated by Favre and Silbermann, which amounted to 2480: then

$$P=\frac{2480}{2\frac{1}{3}\,0.288'+3\frac{1}{3}\,.\,1\frac{1}{3}\,.\,0.275}=1310°\,\text{C.}$$

1 part of carbon combines with $1\frac{1}{3}$rd parts of oxygen to form $2\frac{1}{3}$rd parts of carbonic oxide; the specific heat of this gas is 0.288, that of nitrogen being 0.275.

The specific heats introduced above are those observed by De la Roche and Bernard. Suermann, Apjohn and others have arrived at different numbers for the specific heats of several gases, which, if adopted, will slightly alter the results.

The values of different fuels, as ascertained by Berthier's plan by himself and others, are given in the following tables.

I. WOOD.

Species of wood.	Dried in the ordinary manner. Berthier.		Containing 9 per cent water. Winkler.		Perfectly dried. Schödler and Petersen.			
	lbs. of lead reduced by 1 lb. of wood.	lbs. of water which 1 lb. can heat from 0° to 100° C.	lbs. of lead reduced by 1 lb. of wood.	lbs. of water heated by 1 lb. from 0° to 100° C.	lbs. of oxygen required for the complete combustion of 1 lb.	lbs. of water consequently heated from 0° to 100° C.	Quantity of air at 19° C. required to consume completely 1 lb. in lbs.	in C. F. Hessian.
1 part Oak wood	12.5	28.3	14.05	31.82	1.358	39.82	5.83	154.4
„ Ash „			14.96	33.89	1.356	39.76	5.82	154.2
„ Sycamore „	13.1	29.7	14.16	32.07	1.394	40.85	5.98	148.4
„ Beech „	13.7	31.0	14.00	31.71	1.346	39.44	5.78	152.9
„ Birch „	14.0	31.7	14.08	31.90	1.356	39.73	5.82	153.0
„ Elm „			14.50	32.84	1.418	41.55	6.08	161.1
„ Poplar „			13.04	29.54	1.390	40.72	5.96	157.9
„ Lime tree „			14.48	32.80	1.429	41.87	6.13	162.3
„ Willow „			13.10	29.67	1.352	39.61	5.80	153.6
„ Fir „	14.5	32.8	13.86	31.39	1.408	41.25	6.04	160.0
„ Pine „	13.7	31.0	13.88	31.44	1.392	40.82	5.98	158.2
„ Scotch fir „			13.27	30.06	1.393	40.85	5.98	158.3
„ Hornbeam „	12.5	28.3						
„ Alder „	13.7	31.0						
„ Larch „					1.408	41.25	6.04	160.0

II. CHARCOAL.

lbs. of lead reduced by 1 lb. of charcoal according to Berthier.			lbs. of water heated from 0° to 100° C. by 1 lb. of charcoal.	lbs. of lead reduced by 1 lb. of charcoal.	lbs. of water heated from 0° to 100° C by 1 lb. of charcoal.	Air required for perfect combustion.
				Winkler.		
Commercial	Poplar charcoal	30.60	On an average 68.	33.56	On an average 75.7.	On an average 293.5 C. F. air at 19° C.
	Sycamore „	30.60		33.23		
	Ash „	29.60		33.23		
	Asp „	29.5				
Enclosed in bottles immediately after being made.	Fir „	32.3	On an average 72.	33.51		
	Alder „	32.4				
	Birch „	31.4		33.71		
	Oak „	31.3		33.74		
	Beech „			33.57		
	Elm „			33.26		
	Lime tree „			32.79		
	Willow „			33.49		
	Pine „			33.53		
	Scotch fir „			33.62		

III. PEAT.

Source of the peat.	Berthier. lbs. of lead reduced by 1 lb. of peat.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of peat	Source of the peat.	Winkler. lbs. of lead reduced by 1 lb. of peat.	Winkler. lbs. of water heated from 0° to 100° C. by 1 lb. of peat.
Peat from Troyes .	8.0	18.1			
„ Ham, dép. de la Somme .	12.3	27.9	Among 24 sorts from the Hartz mountains, the worst gave . . .	11.9	26.9
„ Bassy, dép. de la Marne	13.0	29.2	„ „ the best	18.8	42.6
„ Framont, dép. des Vosges	15.4	34.9		Griffith.	
„ Ischoux, dép. des Landes.	15.3	34.6	From Allen in Ireland		
„ Königsbrunn, Wirtemberg	14.3	32.4	„ „ upper	27.7	62.7
			„ „ lower	25.0	56.6
			„ pressed peat	13.7	28.0

Karmarsh in an extended examination of more than 100 varieties of Hanoverian peat, found a considerable difference among the individual kinds, which could not be definitively traced to their age or other properties; with reference to age, however, the following mean values were obtained:

1. Young peat.
   a. yellow grass peat evaporated per lb. 1.78 lbs. of water, and
   b. brown and black peat, 2.03 lbs of water.
2. Old peat.
   a. earthy peat, 1.98 lbs., and
   b. pitch peat, 2.08 lbs. of water. In general, the quantity of water evaporated by 1 lb., ranged between 1.53 lbs. with the worst, and 2.27 lbs. with the best kinds.

IV. PEAT CHARCOAL.

Source.	Berthier. lbs. of lead reduced by 1 lb. of charcoal.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of charcoal.	Source.	Berthier. lbs. of lead reduced by 1 lb. of charcoal.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of charcoal.
Crouy-sur-Ourcq, départ. Seine and Marne . . .	17.7	40.1	Essone, much used in Paris . . .	22.4	50.7
— Ham . . .	18.4	41.7	Framont, and peat from Champ du feu .	26.0	58.9

V. BROWN COAL.

Locality.	Berthier. lbs. of lead reduced from the oxide by 1 lb. of coal.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of coal.
Gemeinde Dauphin, Basses Alpes	25.3	57.3
St. Martin de Vaud, Canton de Vaud	22.6	51.2
Minerme, dép. de l'Aude	22.8	51.6
Gardanne, Bouches du Rhône	22.0	49.8
Fuveau	21.0	47.6
Enfant Dort	21.0	47.6
Koep Fuarch, Lake of Zurich	20.7	46.9
	Kuhnert.	
Brown coal from Meissner	2.01	58.9
Pitch coal from Meissner	1.59	46.6
„ „ Ringkuhl	1.69	49.5
„ „ Habichtswald	1.60	46.9
Glance coal from Ringkuhl	1.93	56.5
Pitch coal from Habichtswald	1 9	43.6
Lowest stratum, Ringkuhl	1 9	43.6
Mid. stra. Ringkuhl	1 0	43.9
Stillberger coal	141	41.3
Lignite from Meissner	147	43.1
„ „ Laubanch	175	51.3

Locality.	Berthier. lbs. of lead reduced from the oxide by 1 lb. of coal.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of coal.
St. Lon, Basses Pyrenees	20.3	46.0
Val-Pineau, dép. Sarthe	19.25	43.6
Common German	1.840	41.7
Edon, dép. de la Charente	17.0	38.5
Alpheus, Greece	16.3	36.9
Triphilis „	16.3	36.9
Kumi „	15.8	38.8
Elbogen, Bohemia	18.2	41.2
	Regnault.	
Earthy coal from Dax	2.138	62.6
„ from Bouches du Rhône	1.889	55.3
„ Lower Alps	1.669	48.9
„ Greece	1.784	52.3
„ Cologne	1.824	53.4
„ Usnach	1.590	46.6
	Varrentrapp.	
Helmstedt, Prinz Wilhelm's mine	2.017	59.1
„ other mines	2.183	63.9
Schöningen, Gr. Treue	1.876	54.9
„ other mines	1.860	54.5

VI. MINERAL COAL.

Locality and kind of coal.	Berthier. lbs. of lead reduced by 1 lb. of coal.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of coal.	Berthier. lbs. of water heated according to the analyses, page 50.	Locality and kind of coal.	Berthier. lbs. of lead reduced by 1 lb. of coal.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of coal.	Berthier. lbs. of water heated according to the analyses, page 50.
a. Caking coal.				Treuil mine, near St. Etienne . . .	25.4	57.5	
Coal from Dowlais, in Wales . . .	31.8	72.0		Bellestat, Aude, called jet	24.4	55.2	
Glamorgan . . .	31.2	70.7		Jet (locality unknown)	23.3	52.8	
Eschwiller, near Aix-la-Chapelle . . .	31.0	70.2	69.7	*b.* Sinter coal.			
Lippe-Schaumburg .	30.9	70.0	80.0	Cherry coal, Derbyshire	27.2	61.6	
Newcastle . . .	30.9	70.0	71.5	Soft coal „ .	26.3	59.5	
Carmeau, near Alby .	30.1	68.2		Oviedo, in Asturia .	26.1	59.1	
Rive de Gier, Grand Croix . . .	29.6	67.0	78.0	Cannel coal from Glasgow . . .	24.9	56.4	
Mons, Bouleau-Fontaine-Madame . .	29.0	65.7		St. Georges di Lavencas, Aveyron . .	24.0	54.5	
Cannel coal, Wigan .	28.3	64.1	76.0	Cannel coal from Lancashire . . .	23.5	53.2	
Mons, Grand-Gaillet .	28.1	63.6		Ombrowa, Silesia .	21.2	48.0	
Rochebelle, near Alais .	27.6	62.5	79.7	Salin, Jura . . .	21.0	47.5	
Mons, nvll. Alliance pit	27.4	62.1		Vazas, Slavonia . .	19.4	43.9	
Bonchamp, Haute Saône	27.3	61.8		*c.* Sand coal.			
Bessèges, Aveyron .	27.0	61.1		Durham . . .	31.6	71.6	
St. Pierre la Cour, near Mayenne . . .	27.0	61.1		Rolduc, near Aix-la-Chapelle . . .	31.0	70.2	80
Epinac, Saône and Loire	26.8	60.7	72.8	Zinsweyer, near Offenberg . . .	22.2	50.3	
From Oviedo, in Asturia	26.1	59.1					

VII. COKE.

Species of coke.	Berthier. lbs. of lead reduced by 1 lb. of coke.	Berthier. lbs. of water heated from 0° to 100° C. by 1 lb. of coke.
A la Garre, from coal of St. Etienne .	28.5	65.6
From coal of Bessèges	28.4	64.3
„ Rive de Gier . . .	26.0	58.9
Gas coke from Paris	22.2	50.3

VIII. ANTHRACITE.

Locality.	Berthier.		
	lbs. of lead reduced by 1 lb. of anthracite.	lbs. of water heated from 0° to 100° by 1 lb. of anthracite.	lbs. of water heated according to analysis.
Anthracite from Lamure, near Grenoble	31.6	71.5	72.8
From Pennsylvania	30.5	69.1	75.6
From Laval { la Chaumière . .	33.0	74.7	
From Laval { la Baconière . .	26.6	60.2	
From Corbattière, in Savoy . .	26.7	60.5	

The value of numerous other fuels as ascertained by this process will be found in some of the preceding tables, or in those at the end of the volume.

One pound of peat requires for complete combustion, according to the determinations and analyses quoted above, from 70 to 134 cubic feet of air at 19° C. (66°.2 F.); medium kinds require 149 cubic feet; 1 lb. of peat charcoal requires 155 to 228 cubic feet; 1 lb. of brown coal, according to the experiments with lead, requires 139 to 222 cubic feet, or 160 to 248 according to analysis; 1 lb. of coal requires by the lead test 170 to 279 cubic feet, average qualities 228 cubic feet, according to the analysis of Richardson from 248 to 303, according to Regnault, those from the coal formation require 320 to 332, those from the secondary formations 293 to 326 cubic feet; 1 lb. of coke requires 194 to 250 cubic feet; 1 lb. of anthracite, according to the lead experiments, requires 233 to 277, according to Regnault's analysis 312 cubic feet. 1 cubic foot of air weighs 0.03794 lbs. at the above temperature.

The numbers which have been cited, and which express the relative quantities of heat given off by different kinds of fuel, at first appear to be in direct contradiction to daily experience. The greatest quantity of heat, for instance, is obtained from the hard woods, while the experiments assign the first place to lime-wood and the softer species. The accurate analyses of Schödler and Petersen explain in a satisfactory manner the observations of practical experience; they show, that although pure woody fibre contains precisely the amount of hydrogen requisite for producing water with the oxygen, or the proportion of 1 of the former to 8 of the latter, yet the woods themselves contain a larger proportion, the excess of hydrogen varying in the different kinds. Thus the 44.5 parts of oxygen in oak-wood, require $\frac{44.5}{8}=5.562$ parts of hydrogen to form water; the wood contains, however, 6.07 per cent, or $6.07-5.562=0.508$ per cent more than is requisite to produce water,

which is equivalent to 5.08 parts in 1000. In like manner, we find hydrogen in excess in the following woods, in 1000 parts:

Excess of hydrogen.	Excess of hydrogen.	Excess of hydrogen.	Excess of hydrogen.
Oak-wood . 5.08	Beech-wood 6.50	Poplar-wood 8.20	Deal . . . 9.50
Ash . . . 5.05	Birch . . 7.50	Lime-wood 13.90	Pine-wood . 8.80
Maple . . . 8.30	Elm . . . 10.00	Willow . . 7.00	Scotch-fir . 7.70
			Larch . . . 8.60

This excess of hydrogen will give rise to the formation of gaseous hydro-carbons when the wood is heated, thus removing a considerable portion of carbon and proportionally diminishing the residual charcoal. It is principally these gases and vapours which burn so readily, and produce the flame. The lighter kinds of wood are, therefore, characterized chemically by a larger excess of hydrogen, which causes the first stage of their combustion (*combustion with flame*) to be augmented at the expense of the second—the *incandescence of the charcoal;* they consequently burn with greater facility, or *evolve their heat in a shorter space of time* than the hard woods. This property may very properly be called that of *greater combustibility,* and the heat given out must necessarily be greater, as hydrogen requires more oxygen for perfect combustion than carbon, and evolves considerably more heat. Our arrangements for applying heat, however, are generally of such a nature as to require time for the communication of the heat evolved by the fuel. If the evolution is too rapid, the necessary time is not allowed, and much heat escapes without serving any useful purpose. Hard woods are therefore preferred for most purposes, because the softer kinds evolve the greater quantity of heat they are capable of producing in such a manner as to be useless in the furnace, and not from any actual deficiency in their heating power. Whenever a very intense heat is required, as, for example, in the porcelain kilns, the preference is given to the soft woods. These remarks are equally applicable to other kinds of fuel.

The time required for combustion, and consequently for the evolution of heat, is also dependent upon the state of division of the fuel. A certain weight of wood, for example, in the form of shavings, comes much more rapidly in contact with the air than when in the form of a single compact piece. In the former case, many more portions of the wood will burn simultaneously than in the latter, and the evolution of heat will cease in a comparatively short space of time. While the compact log is slowly consumed, and is capable of keeping the surrounding parts (the

sides of the furnace) at a moderate temperature for hours, the shavings will bring it to a red heat, although only for a few minutes. This circumstance is of great importance in practice, and accounts for the preference given to the Newcastle Steam Coal over the Welsh. The combustibility of the fuel, however, or the quantity which is consumed within a given time, is not increased by too great a subdivision, which leads to a directly opposite result, and ultimately, if carried to an extreme, renders the fuel absolutely incombustible. Charcoal powder, sawdust, crushed coal of the best quality, powdered peat, &c., cease to be combustible bodies, because, whatever kind of grate may be used, the small particles lie so closely together that they prevent the access of air. They are consequently valueless, unless the surface of the grates can be covered with blocks of sandstone, limestone, or some similar material, so as to prevent the powder from falling through the grate, and yet allow the access of air, as is done in some boiler-fires and glass furnaces in the neighbourhood of Newcastle-upon-Tyne.

Fuel in this finely-divided state has been rendered available, however, by various mechanical contrivances, fully described above under Patent Fuel, and in this state appears to offer some advantages over the raw material, which will, under certain circumstances, compensate for its higher price. Thus the Carboleine of Weschnaekoff, as well as the other patent fuels, although considerably more costly than coal, may, from their superior heating power and small bulk, be employed with advantage in steam navigation. As an example, we may suppose a steamer of 1000 horse-power, requiring for one journey 81,884 cubic feet (2240 tons) of coal; now, according to the observations which have been made, 0.643 parts of Carboleine will do the work of 1 part of coal, while in addition the relative volumes of equal weights are as 0.98 to 1. Sixty-three cubic feet of Carboleine will, therefore, effect as much as 100 cubic feet of coal, or 51,587 cubic feet will be sufficient for one journey, leaving (81,884—51,587) about 30,000 cubic feet of the ship's space unoccupied. If the freight be calculated per cubic foot, and each cubic foot is charged at the rate of 5*s*., there will be a saving of about £6,959, after deducting £641 as the extra price of the Carboleine.

The above experimental results exhibit the comparative quantities of heat which can possibly be obtained from fuel, expressed in quantities of water raised by its means from 0° to 100° C. in

temperature; they therefore express the greatest possible amount of heat which these can produce. If the quantity of heat, actually obtained in pratice, and made available in the arts and manufactures, be compared with this, it will be found exceedingly small. A considerable portion of the heat, therefore, which is dormant in the fuel, is either not evolved in practice, or is lost by the mode of application. Both cases occur; but in order to discover the sources of this loss, it will be necessary to examine the principles upon which the application of heat depends.

ON THE APPLICATION OF FUEL.

It is beyond the scope of the present volume to enter into full details upon the various methods that have been introduced for the application of fuel to the several wants of the different branches of manufacture. In many of these, the heat generated, not only performs the office of raising the temperature and changing the physical condition of the substances operated upon, but very frequently, as in smelting, roasting, and other processes, brings chemical affinities into play which are not active at low temperatures. Under each branch of chemical manufacture, we propose to give a particular account of the heating or other arrangements in which fuel is employed, while at present we shall confine our attention firstly, to those plans which have been most generally adopted, or which recommend themselves to our notice, for securing an uniform temperature in private dwellings, or public buildings at all seasons, while they promote the equally important object of an efficient ventilation; and secondly, to a few illustrations of the mode of application of fuel in the more important processes of the arts or manufacture in which it is essential.

In order to render a room or dwelling comfortable, the air contained in the entire space must be kept as far as possible at a uniform temperature, ranging from 56° to 70° F., considerably higher, therefore, than that of the atmosphere during winter in most civilized countries. When air is warmed it expands and becomes lighter, and being a bad conductor of heat a constant current is produced in any confined space into which a hot body is introduced. The warmer portions ascend and give place to the colder, as long as the inequality of temperature continues, so that the internal temperature of a room can never be retained above that of the colder exterior without a constant circulation of the enclosed air.

The velocity acquired by this current depends upon the extent of the heating surface employed, and upon the difference of temperature between it and the air of the room; it is not, however, in direct proportion, but in the ratio of the square root. If the air in the room, for example, is 60° F., and the surface of the stove at one time 176° F., and at another 212° F., the current in the latter case will be $\sqrt{\frac{176-60}{212-60}}=\frac{1}{1.14}$ more rapid. Again, as heat from any source is communicated by radiation, as well as by conduction, the more distant layers of air become warmed by contact with bodies heated in this manner, and ascend in consequence. Rooms might be easily and quickly heated at a small cost of fuel, if several unavoidable circumstances did not combine to withdraw the heated air and diminish its temperature. In the first place, the walls of the room, the windows, and doors, constantly absorb heat, and evolve it again externally; secondly, the air in the interior being warmer and lighter, and consequently not in equilibrium with the external air, all crevices in windows and doors will allow cold air to stream in from below, while hot air passes out above; lastly, in order to render the atmosphere healthy and fit for respiration, it is absolutely necessary that the air which has once passed through the lungs and the skin should be replaced by fresh air, which must generally be supplied cold from the outside. According to Munke's estimate, the loss of heat from these causes, after deducting what is necessarily incurred for ventilation, amounts in twelve hours to 5 times, and according to another estimate, to 6 times the quantity of heat that is required to raise the temperature of the air confined in a room of ordinary dimensions to 68° F. Every special case, however, will require a separate estimate. This loss is partly compensated by the vital heat of the persons present in the room, as also by the lamps and candles which are burnt; but it is certain that the greater part of the fuel required for retaining the air of a room at the proper temperature is consumed in making up for this constant loss of heat. Double windows and doors, and similar contrivances, which enclose a stagnating layer of air, materially lessen the loss of heat. During the time that a door is open, the warm air may be observed to stream out from above, and the cold to enter from below, by holding a lighted taper in the two regions, the current being more rapid, the greater the difference of temperature between the external and internal air. It is found very advantageous to allow

the doors to open upon warmed ante-rooms, when warm instead of cold air is admitted. The loss of heat occasioned from these circumstances may be approximatively ascertained by observing how much the temperature of a room sinks in a given time after the extinction of the fire.

When the air of a room is to be heated, the surface from which the heat is evolved is constructed so as to combine the necessary arrangements for the combustion of the fuel and the conduction of the heat. All the contrivances for communicating heat to apartments, however they may vary in outward form and dimensions, comprise a space for the combustion of the fuel; an area from which the heat is diffused; and lastly, some means of creating a draught, generally a chimney or flue, to draw the necessary air and carry away the products of combustion. The two primary conditions which are essential to every arrangement are, the maintenance of a temperature capable of consuming the material, and the supply of the amount of air (oxygen) necessary for combustion. If either of these be neglected, as they invariably are to a certain extent in practice, imperfect combustion is the result, and a consequent defective evolution of heat.

Chimneys.—The air that is required for combustion is sometimes supplied, as in metallurgic processes, by machines for the purpose, but in most cases, as in room-stoves, kitchen-ranges, copper-fires, &c., the heat itself is made subservient to the production of a draught by means of a chimney. A *chimney* is a narrow channel, situated and extending to some height above the spot where combustion is going on, and the diameter of which, whatever may be its form, must correspond, within certain limits, with the size of the fire, and communicate freely, above and below, with the air. The column of air which occupies the interior of the chimney, is, when cold, in equilibrium with a column of equal magnitude without; a condition which ceases, however, as soon as the fire begins to warm the internal column, expanding it, and rendering it lighter. The equilibrium being then destroyed, the external air enters the space left vacant by the ascending inner column, is again heated in its turn, and gives place to another quantity of cold air, and so on; in short, a draught is created which lasts during the whole time of combustion. The difference of weight between the external and internal column of air is increased or diminished with the height of the chimney, and its temperature. We know that air is expanded $\frac{1}{490}$th of its volume for every additional 1° F. of temperature; in

a channel of equable diameter, this may be measured directly by the height. If h represent the height of the chimney, t the difference of temperature between the external and internal column of air, we have $h-\frac{ht}{459}=h\left(1-\frac{t}{459}\right)=h'$, as the height of the internal column of air, supposing it to have the same temperature as the external. The former is therefore shorter than the latter, by $h-h'$, or $h-h\left(1-\frac{t}{459}\right)=\frac{ht}{459}$, a difference of height through which the latter must fall in order to enter the chimney. The velocity which it has acquired at the end of its descent, is just that with which the air in the chimney is moving, and according to the law of falling bodies, just double that of the acceleration gained during the descent.* In the supposed instance, where $s=\frac{ht}{459}$, we have, therefore, $c=2\sqrt{g\frac{ht}{459}}$ as the velocity, which must obtain, according to theory. The formula, however, is based upon assumed conditions, which are never actually present in practice, and experience has shown that the real velocity in a chimney, on account of irregularity in the walls, and retarded flow of air through grate and fuel, as well as on account of the altered chemical nature of the latter, &c., remains so far behind the theoretically calculated velocity, that the latter cannot be employed to represent it with accuracy.

The retarding influences may partly be made the subject of calculation, so far at least as is necessary to understand the mode of their operation. The friction which the current of air suffers against the inner sides of the chimney, is an obstacle of some importance; the force of the current is partially broken by coming in contact with the rough sides, and the velocity is lessened as the number of the irregularities increases; the height of the chimney, the force with which the reverberation occurs, or the velocity of the current, and lastly, the nature of the material composing the chimney, will all influence the ultimate result. Common brickwork, covered with

* If g represent the space which is traversed in a second (15 feet), t the duration of the descent in seconds, s the space passed through in the time t, and c the acquired velocity, we obtain $c=2gt$. And because the space traversed is proportional to the square of the time occupied, or $s=gt^2$, it follows that

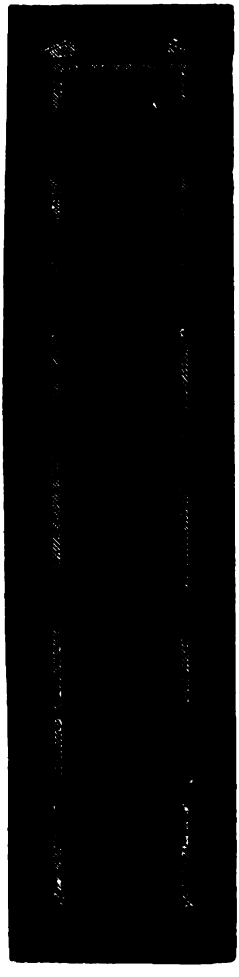
$$t=\sqrt{\frac{s}{g}}, \text{ and hence } c=2g\sqrt{\frac{s}{g}}=2\sqrt{gs}.$$

mortar, offers much more resistance than cast- or sheet-iron. A narrow chimney, under the same circumstances, will offer more resistance than a wide one, as in the latter a greater portion of the column of air will pass through the centre of the chimney, and not touch the sides. In a very narrow channel, every particle of air may come in contact with the sides. The friction, therefore, is generally diminished by an increase in diameter. The actual velocity of the current has been found considerably below what it should be according to calculation, even when the retarding influences the amount of which have been determined by experiment, are taken into consideration. Various other causes may be adduced to account for this diminished velocity, such as the want of regularity in the supply, the accumulation of soot in the chimney, stoppage of the grate by ash, which are unavoidably connected with the practical use of fuel.

It is interesting to know to what extent the friction in a chimney may be practically lessened by increasing its diameter and augmenting the internal temperature. It was stated above that the disadvantages attending the heightening of a chimney may be counteracted by widening at the same time; but calculation proves that this must very soon find a limit, as does indeed occur when the height of the (round) chimney exceeds its diameter 30 or 40 times. By an ingenious contrivance, these narrow limits have been extended. The contrivance is this: the entrance of the chimney remaining unchanged in dimensions, the upper part is suddenly considerably widened, the extended diameter being preserved throughout its entire length; thus the necessary quantity of air passes through the grate and fuel with undiminished velocity — and this is the real object of the draught—but spreading itself out afterwards in the wider channel, it ascends more slowly and with proportionally diminished friction. It may be shown by calculation that the greatest advantage is obtained when the mouth is $\frac{1}{4}$th the width of the chimney. An increase of width obviously involves an extension of the mass of brickwork, and with it the amount of cooling must also increase. There will, therefore, be a certain ratio between these, when the advantage of diminished friction will be counterbalanced by the disadvantage of cooling. The principle upon which chimneys are constructed, supposes the draught to increase in proportion as the temperature of the internal exceeds that of the external column of air; this, however, occurs in a lesser proportion (in the ratio of the square root) than the increase of temperature;

so that above 250° (482° F.) no increase of draught is obtained when the height of the chimney is 20 times its breadth. When one portion of the chimney is horizontal, no great difference in its action is observable, provided the entire height be not diminished; but the friction and cooling effects are somewhat increased. All contractions above the entrance or mouth must, however, be carefully avoided. Wind often materially interferes with the draught in chimneys, and its action is difficult to overcome; it may sometimes be counteracted by heightening the chimney and increasing the draught, or by adapting some arrangement to the summit, to prevent the pressure it exerts from acting below a certain height. The circumstance that the rays of the sun falling at certain times upon the fire will retard the draught, or force back the smoke, has not been satisfactorily explained.

FIG. 89.



Manufacturers are in the habit of building their chimneys of such diameter and capacity as will more than suffice for the work to be done, in order that an increase of work may not involve the expense of an additional chimney, the flues from new furnaces being carried into the general stack. When this precaution has not been observed, the old erection may be made capable of effecting more work by inclosing it with an outer wall, as in the following case.

The chimney constructed at Mr. Cubitt's works, at Millbank, Fig. 89, having been found, as originally erected, insufficient for the work which it afterwards had to perform, and its strength being incapable of bearing any addition to its height, it was enclosed in the tower, which is now an ornament to that part of the metropolis. The draught is now more than adequate for all the extra work which has to be performed, and the saving of the heat previously lost by radiation, has effected a considerable reduction in the quantity of fuel consumed.

The temperature of the interior, about one-third up, is 450°, and at the top 213° F. The expansion during the week is very considerable from the accumulation of heat, and the interior of the tower is maintained at summer temperature by the radiation of the heat from the sides of the chimney.

Fire-grate.—The most important part of the fire-place is the support for the fuel; it is generally constructed of iron bars, which admit air to the fuel, and is called the *grate*. The spaces between the bars of the grate should be wide enough to allow the ash to fall through, and at the same time sufficiently contracted to support the fuel. In many stoves and boiler fires no other entrance to the chimney is afforded except through the bars, and their shape as well as the distance between them, exert considerable influence upon the draught. The bars should be wedge-shaped, the wide side of the wedge being placed uppermost in the grate, and the total area for the admission of air between them should be, with reference to the diameter of the chimney, in the ratio of 1 : 4. As, however, a great part of the open grate surface is necessarily clogged with fuel while the process of combustion is going on, and some fuels offer much more impediment to the draught than others, no data generally applicable for the construction of grates, with reference to the relative areas of open grate surface and chimney vent can be given, although as a near approach to the ratio above stated, the practical rule is to leave an open grate surface equal in dimensions to the diameter of the flue. The greater the heating power of the fuel, the wider may be the grate, and *vice versâ*. No grate is absolutely requisite when wood is used, the necessary air being admitted by holes in the door. The shape of the grate is of less importance; but when it aids the uniform sinking of the fuel, and is deepened or basket-shaped, it may materially assist the process of combustion. A very superior form of grate for large boiler fires will be described below, in connection with the consumption of smoke.

Methods of Heating Apartments and Dwellings.—In order thoroughly to understand the principles of applying heat, it is necessary to remember that the heat evolved from fuel is disseminated to surrounding bodies in two ways, by *radiation* and by *immediate contact*. Peclet has examined these points, with the aid of a very ingenious apparatus. He surrounded fuel, contained in a round wire basket, with a ring-shaped vessel, in such a manner that the quantity of water contained in the latter could only be heated by

radiation from the surface of the globular basket. By comparing the size of the radiating surface with the quantity and the temperature of the heated water, it was found that the radiated heat from wood was $\frac{1}{4}$th, from wood charcoal $\frac{1}{8}$, from coal about as much, and from peat and peat charcoal $\frac{1}{12}$th of the whole amount of heat evolved. As a general result, the combustibles which burnt with the least flame yielded the most radiant heat. The radiant heat is therefore nearly always the smaller quantity, and on that account, the arrangements in which it alone is employed, are not economical for heating the air of dwellings.

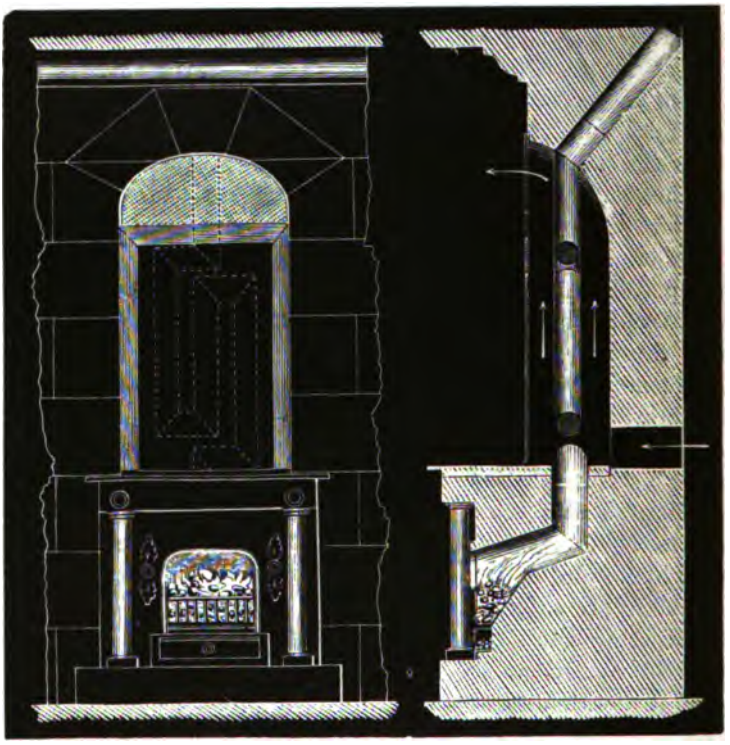
Open Fireplace.—The open fire-place, or hearth, is the most ancient mode of heating dwellings, and although it only affords radiant heat to the room, is still very generally employed in France and England. The fire-basket, or grate, is placed immediately below the chimney, which is widened into a recess to receive it; the fire thus burns unenclosed in the room, whence it draws the necessary air for the combustion of the fuel; the air becomes heated and passes off with the smoke into the chimney, without parting with any portion of its heat to the atmosphere of the room. It is almost impossible to regulate the quantity of air supplied to an open fire-place, and a considerable portion of the warmed air of the room is uselessly carried off by the draught. Thus the only way in which the fire can warm the air is by radiation. All the improvements made by Rumford and others upon open grates, tend to facilitate radiation towards the room, to make use of the escaping air as much as possible without injuring the draught, and lastly, to regulate the draught. The grate is frequently brought forward from the wall of the chimney, and the sides of the recess are so constructed that their inner surface, acting like the reflector of a lamp, shall collect the rays of heat and reflect them into the room; the size of the recess is sometimes lessened and fitted with dampers to prevent loss of heat, which, however, must always be very considerable in every open fire-place.

Numerous contrivances have at different times been invented for economizing the heat of the smoke and gases, which, in the ordinary arrangement of the open fire-place, pass directly into the chimney without parting with any portion of their heat. One such is shown in Figs. 90 and 91, adapted to a coal fire. The products of combustion here ascend through an iron pipe, which may be lengthened by bends to increase the heating surface.

This pipe is placed in a cavity of the wall above the mantel,

which is connected at the lower extremity with a channel which communicates with the external air. Fresh air is thus warmed by contact with the pipe conveying the smoke and heated gases, and delivered into the room through a grating in connection with the upper part of the cavity. The objections to all such arrangements consist in the difficulty of cleaning the pipes, and the danger of mixing smoke with the fresh air from imperfection in the joints.

FIG. 90. FIG. 91.



A stove fire-place, which combines the advantages of the open grate with those of the close stove, has been invented by Desarnod. It is constructed of plate-iron, and stands forward and isolated in the room, an iron plate being fixed at the back, through a slit in which the smoke passes to a series of pipes, which it traverses before being carried to the chimney. The room is then warmed, not only by radiation, but also by the immediate contact of the air of the room

with the heated iron plate and the pipe in which the smoke circulates. Desarnod's stove fire-place is very similar in principle to that described below.

The numerous advantages of an open fire-place are so highly valued by the inhabitants of this country, whose ideas of comfort and sociability are intimately connected with the fire-side, that it is not likely that other modes of heating rooms or dwellings will ever entirely supersede this old-established plan of obtaining the necessary amount of warmth. The open fire-place and chimney afford the simplest possible means of creating a thorough circulation of air throughout the inhabited room, with which it is impossible to dispense without injury to health, and which is entirely absent in those arrangements on the continent, where the fuel is introduced into the stove and supplied with the requisite amount of air from without. The ventilation of the rooms is then entirely dependent upon crevices in windows and doors, and as these are avoided as much as possible in the construction of the houses, double windows and double doors being frequently employed, the air becomes vitiated in a very short time, especially where many persons are present, and the sallow complexions and stove-dried appearance of the occupants of such dwelling-rooms is one of the visible signs of their injurious tendency.

The ordinary arrangement of the fire-places in our dwelling-houses at present, however, is very defective. There is always a considerable loss of heat, the very unequal temperature diffused through the different parts of a room being exclusively derived from the radiant heat of an open fire. The only supply of air to the fuel is furnished by the crevices in doors, windows, or floors; and persons sitting by the fire, invariably experience the unpleasant sensation of excessive heat on the side exposed to it, while the other is cooled to an equally disagreeable extent by cold air rushing in from these different sources to maintain the combustion of the fuel. Another objection to open fireplaces and chimneys, is the downward draught frequently occasioned in neighbouring chimneys not in use, by large powerful fires in other rooms of the same building, which are not supplied from other sources with sufficient air for the consumption of the fuel. Foul air, carrying with it particles of soot, is thus disseminated through the rooms, to the detriment of health and cleanliness.

The late Mr. Sylvester made several improvements upon the open fire-hearth, which have been adopted with great advantage in

many public offices as well as in private houses. In Sylvester's stoves the fuel is placed upon a grate, the bars of which are on a level with the floor of the room, and air is supplied to the ash-pit below by a series of passages which pass under a hearth composed either of separate bars of iron, arranged in a radiating manner in front of the grate, or of ornamental fire-tiles. The radiant and conducted heat from the fire is thus made to warm the hearth and the air passing below it, while the low position of the fire, and the inclination which may be given to the back and sides of the grate, tend to disseminate the heat much more effectually through the room than is usual in the ordinary arrangement of the fire-place. The sides and top of these stoves are constructed of double casings of iron, and in the sides a series of vertical plates are enclosed, parallel with the front facing, which collect, by conduction, a great portion of the heat generated from the fire, the mass of metal of which these are composed being so proportioned to the fuel consumed, that the air can never rise above the temperature of 212° F. under any circumstances. The sides and top of the stove are thus converted into a hot chamber, offering an extensive surface of heated metal; at the bottom, by an opening in the ornamental part, the air is allowed to enter, and rises as it becomes warmed, traversing in its ascent the different compartments formed by the hot parallel plates, and is allowed to escape at the top by some similar opening into the room. A current of air is thus constantly traversing the hollow

FIG. 92.

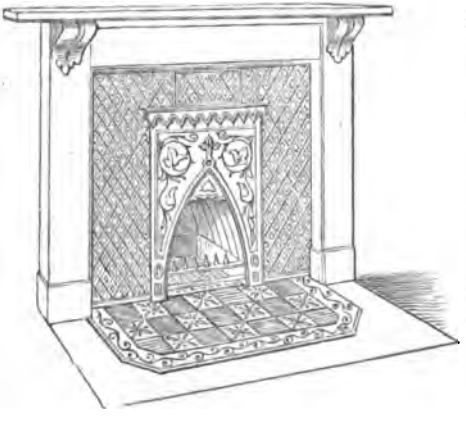


FIG. 93.

sides and top of the stove, collecting the heat communicated to the metallic mass and disseminating it through the room. If allowed to enter the room by the top aperture, the air would now be in the rarified, dry state, which is considered unwholesome; a basin of water is consequently introduced into the top of the stove, where it evaporates, communicating the proper amount of moisture to the air. Figs. 92 and 93 represent two of these stoves: the one, Fig. 93, is intended to stand forward in the room; the other, Fig. 92, to fit into the recess of an ordinary chimney. At the back of the grate is a series of louvres, by opening or closing which, a greater or lesser draught can be created, according to the amount of combustion required. The whole opening into the flue behind can be closed when the fire is not in use, by sliding doors, shown in Fig. 94, which form a valuable addition to every chimney,

FIG. 94.

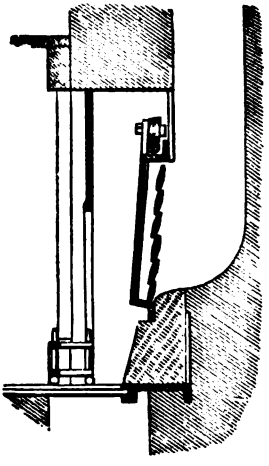
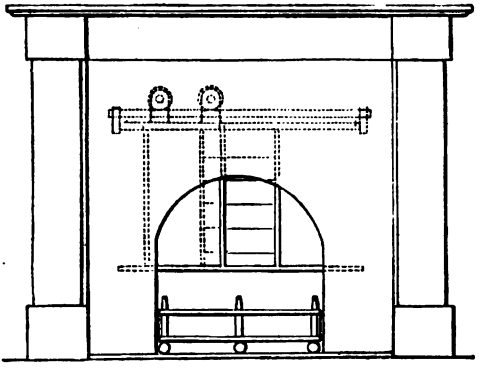


FIG. 95.

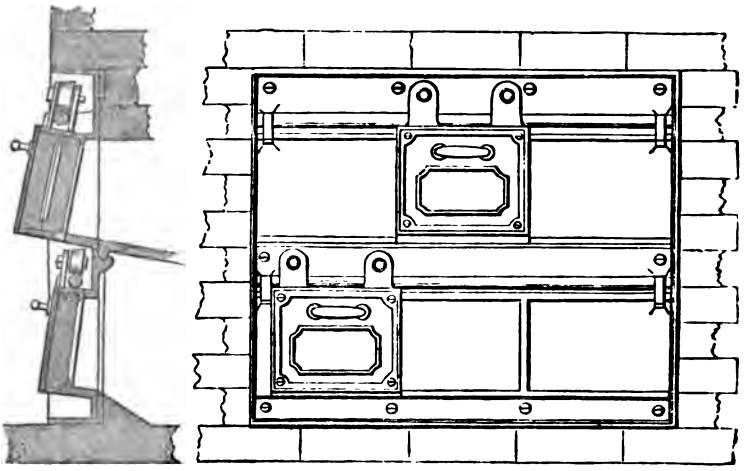


and deserve more particular notice from their important applications to other technical purposes connected with the economical use of fuel. These doors are constructed in such a manner that they slide perfectly true upon the surface of metal behind them, a portion of their weight being distributed against the sliding surface, for the purpose of preserving contact; they are provided also with friction rollers to support them on their bearing bar, in order that they may be easily moved. Chimneys not in use can be completely closed by this contrivance, and the disagreeable downward currents, mentioned above, are most effectually stopped by closing the door.

These doors will also be found of much service in the case of a chimney taking fire, for by closing the door all air is prevented access to the burning soot, and the fire speedily extinguished.

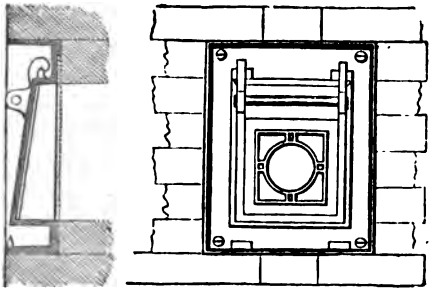
Applied to furnace or boiler fires and ash-pits, in the manner represented at Fig. 96, they afford a means of regulating the

FIG. 96.



draught with great nicety, and thus supply one of the most important conditions for moderating the combustion of fuel. For these purposes they may be lined with fire-brick or clay.

FIG. 97.



The same contrivance, Fig. 97, is applied to the soot or flue doors, introduced into chimneys for the purposes of cleansing, which can thus be accurately closed, and side currents prevented.

The economy of heat and fuel is very great in the stoves or fire-grates just described, but the air which supports combustion is supplied in the ordinary manner from adventitious sources, and the only mode of remedying this, with proper attention to ventilation at the same time, is by affording a distinct entrance to pure air from

without the building by some passage made expressly for that purpose. Mr. Sylvester recommends that a subterranean passage be made from the basement of every house to the garden, that the entrance to this passage be furnished with a revolving hood, which turns easily and presents an opening to the wind. The air which enters this passage is caused to traverse the heated sides of a large stove, constructed upon the principle described above and conveyed from thence to the passages and rooms of the whole house. The entrance of air by chance apertures and crevices is thus rendered unnecessary, and if the supply from the air-channel be sufficient, there will be a tendency in the air to escape rather than enter. Cold currents of air will then be replaced when required by warm currents, the circulation being kept up by small fires in each inhabited room, while the lesser consumption of fuel in each apartment will compensate for that consumed in the stove for heating the general supply of air.

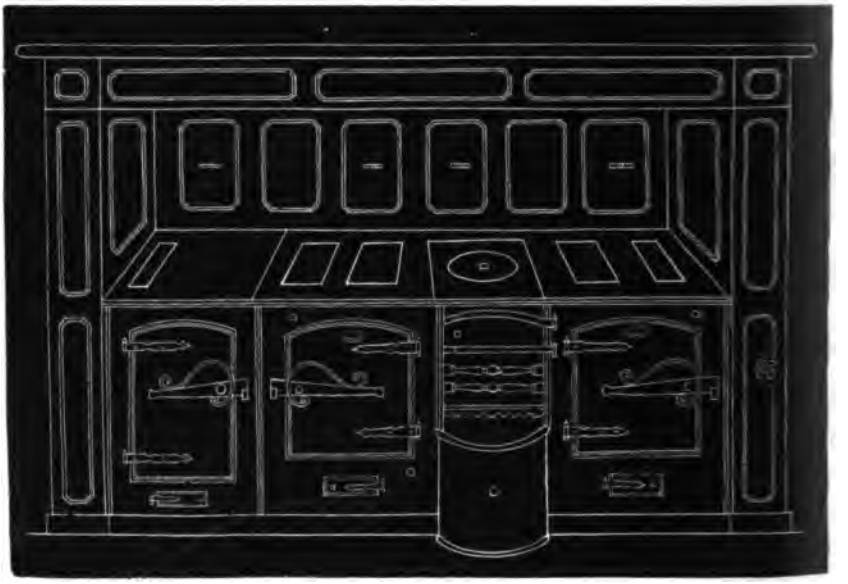
Some stoves or furnaces adapted for heating large volumes of air will be described below, in connection with the methods employed for warming and ventilating public buildings and spaces of large area, for which the radiant heat from open fire-places is totally insufficient.

The open fire-place is by no means adapted for cooking purposes, although scarcely any other arrangement is ever seen in the kitchens of this country. On the continent, where wood or charcoal is the only fuel, and is both scarce and expensive, the economical application of it is much better understood. Count Rumford wrote elaborate essays upon the construction of kitchen and other fire-places, ovens, roasters, &c., which have, however, produced but little effect upon the general practice of the country, builders and house-fitters still clinging most tenaciously to an immoderate use of iron in the construction of grates of all kinds. He strongly recommends a separate small fire for each oven, boiler or roaster, and avoids the use of iron in the construction of the fire-places as much as possible.

The sketch below, Fig. 98, shows the arrangement of a kitchen range, which obtained a prize at the Great Exhibition of 1851. The fireplace is covered by an iron plate, in the centre of which, immediately above the fire, is a circular aperture closed by a disc of metal, when not occupied by the cooking utensils. The fire is only exposed at the bottom and front, and the upper part of the front, usually occupied by bars, can be shut by a short door,

which converts the fireplace into a kind of furnace, the smoke being allowed to escape either through a flue immediately behind the fire into a common chimney or through one of the other flues terminating in the same and indicated by the positions of the several dampers at the back in the drawing. By means of this series of flues and dampers, the flame and hot gases can be carried round one or more of the ovens which are situated on either side

FIG. 98.



of the fire, while a boiler at the back and on one side, with a supply-pipe to keep it constantly filled with water from a cistern, furnishes a constant supply of hot water.

Stoves.—Chamber stoves are constructed to disseminate heat by the direct contact of air with the heated surface, which is obtained by burning fuel on a grate, closely surrounded on all sides except below the bars, by a good conducting or absorbing material. The most important part of the stove, which is entirely absent in the common open fireplace, is the chamber or series of flues through which the smoke passes, and which, becoming heated, communicates this heat directly to the air. The communication between the chimney and the hot chamber of the stove is generally effected by means of sheet-iron pipes, which also aid in the dissemination

of heat. In the greater number of dwelling-houses the chimneys are wide enough for a man to ascend them for the purpose of sweeping, and exceed the proper dimensions for providing a draught; they thus only serve to carry off the smoke, and the draught must be produced by a smoke-pipe. This pipe ascending in the room, and surrounded by air, may be viewed as a continuation of the hot chamber, and adds very much to the effect produced by the latter. The hot air chamber of stoves should be correctly proportioned to the quantity of fuel consumed; it must also vary with the size of the room and the loss of heat from ventilation and radiation through walls and windows. The materials used for the construction of stoves are cast iron, sheet iron, bricks and tiles, and in order to calculate the requisite amount of surface, it is necessary to know the relative degree of facility with which these communicate the heat they receive. We know, from daily experience, that iron conducts and communicates heat much more readily than clay. This power of communicating heat depends, first upon the power of conduction of the material, which, according to Despretz, is nearly 33 times greater in iron than in clay, and secondly upon the nature of its surface,* for the heat has to be communicated not only from particle to particle throughout the material of the chamber, but also from its surface to the air, and this is partly effected by contact and partly by radiation, the different surfaces acting very differently in this respect. The communication of heat from the surface to the air, by the joint effect of radiation and contact, is, according to Peclet, in sheet iron 1.21 times, and in cast iron twice as rapid as in clay. Iron stoves, therefore, both heat and cool more quickly than stoves constructed with bricks or tiles, and the latter must present a much larger surface than the former in order to produce an equal effect.

When the fuel is rapidly burnt in a stove, so as to evolve at once the entire amount of heat it is capable of affording, the temperature produced is far greater than is required. Iron, therefore, which conducts and evolves heat almost as rapidly as it is received, is not an appropriate material for communicating an uniform temperature of about 68° F., as required in a dwelling. Clay is decidedly preferable, for, with whatever degree of rapidity its

* Peclet has corroborated this statement by recent experiments, according to which, plates of 1 square metre surface, and 1 mm. thick, at a temperature of 1° C., allow heat to pass through in the case of clay and iron as $0.24 : 7.95 = 1 : 33.1$.

temperature is raised, it evolves the heat much more slowly and gradually. Clay, or bricks and tiles prepared from it, amass or accumulate heat, and evolve it in a very regular and gradual manner, which renders them peculiarly well adapted for the construction of stoves. It is often objected to iron stoves that they occasion an unpleasant smell in the room, and produce headache and other disagreeable sensations. The smell is chiefly produced when some portion of the stove, by want of attention, is allowed to become red-hot, and the particles of dust always floating in the air, coming into contact with the red-hot surface, are charred or burned; some slight smell, however, is said to be produced by the iron itself. If water is not placed on a stove which is liable to be strongly heated, the air is warmed without acquiring an amount of moisture commensurate with its increased temperature, when it will exert a drying action upon the skin and all bodies exposed to it, to which action the unpleasant sensations may in part be ascribed.

In this country, and in many parts of the continent, and in America, iron is the material almost universally chosen for the construction of stoves, chiefly on account of its comparative cheapness and durability and the facility which it affords for the manufacture of portable stoves on a large scale. Stoves constructed of Dutch tiles or clay are extensively used in Russia, Sweden, and the central parts of Europe; in these the heat accumulated during the combustion of the fuel is gradually given off to the surrounding air. Clay stoves are necessarily much more bulky than those made of iron. From the given quantity of air (=A) which the stove must hourly heat (to t°) to make up for the loss by cooling and ventilation, the corresponding amount of clay surface may easily be calculated. The mean weight of 1 cubic foot of clay is 62 lbs.; 1 cubic foot of air, at 68° F., weighs 0.037 lbs.; therefore, 1680 times less than an equal bulk of clay, the same amount of heat produces the same rise of temperature in equal masses of both bodies, the specific heat of air and of clay being nearly $\frac{1}{4}$th that of water. The heat, therefore, required to raise 1680 cubic feet of air to the desired temperature, or t° above the external air, will be sufficient to produce the same effect in 1 cubic foot of clay. The latter, however, becomes much hotter by the action of the fire, and warms the air of the room by cooling gradually from a maximum temperature =T° to a temperature t'°, which is still sensibly higher than t°. The heat evolved during

cooling will warm a greater body of air to t° in the ratio of $t° : (T-t')°$, whence we obtain $Q = \frac{A\,t°}{(T-t')°\,1680}$ as the volume of clay corresponding to the body of air to be heated.

In stoves of the simplest construction, the fire is surrounded directly by the surface to be heated, which, being placed unprotected in the room, radiates heat and warms the air by direct contact, the smoke passing away through a pipe into the chimney. The greater part of the heat communicated is in this case due to radiation, and the direction in which the pipe carries away the smoke and heated air, whether it be placed perpendicularly above the fire, horizontally, or in a downward direction before entering the chimney, is not of material consequence as far as the actual amount of heat evolved is concerned, provided the same extent of surface is exposed and a proper draught secured. The material of which the stove and the smoke-pipes are composed, will of course exert considerable influence upon the quantity of heat evolved. The pipes should be of somewhat less diameter than the minimum diameter of the chimney, not sufficiently extensive to cool the smoke too much and thus endanger the draught, nor too contracted to evolve it at a higher temperature than is required, and so cause a loss of heat: from 4 to 8 inches diameter, according to the amount of fuel to be consumed, are the most convenient dimensions.

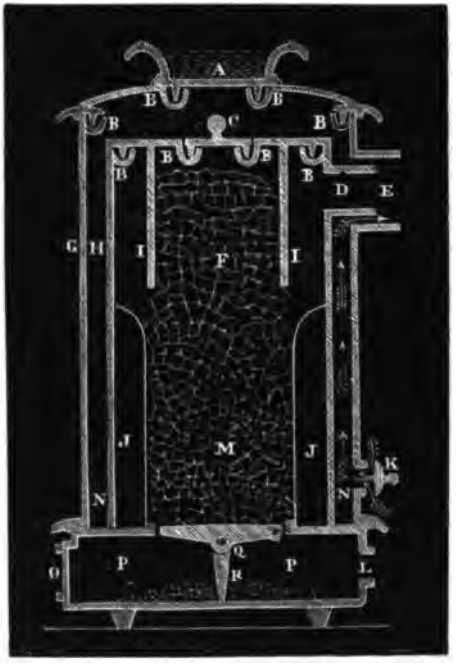
The relative heating surface required for any given space or known amount of cooling action may be calculated approximately for practical purposes from the facts established by Peclet, that a square foot of sheet iron, freely exposed to the air, will evolve, by the joint action of radiation and contact, about 160 to 200 units of heat per hour; a square foot of cast iron from 400 to 500; and bricks or tiles, $\frac{1}{10}$ths of an inch in thickness, from 150 to 180, supposing the combustible to be consumed in such a manner as to exert in each case 0.8 of its heating power.

The common metal stoves frequently employed in halls, churches, and other public buildings in this country, are of this simple construction, and are very liable to be overheated when not properly managed. They then give rise to the unpleasant sensations above described; and even when carefully tended, so that no perceptible smell or noxious vapour is evolved, are seriously objected to by many who have been accustomed to the direct heat of an open fire. Whether this antipathy to stove-heat arises from mere prejudice, or a really different effect is produced upon a sensitive human body

by the rays of lower intensity and lesser refrangibility, which emanate from heated iron, it is at present impossible to decide.

A detailed description of the simple stove is quite unnecessary, nor will our limits admit of more than a few illustrations of the almost innumerable methods which have been resorted to by different inventors for economising the heat from the stove and adapting it to different kinds of fuel. As a very economical and, when properly managed, convenient modification, we may mention the stove of Dr. Arnott, a sectional drawing of which is shown in Fig. 99. *G* is the outer iron case of the stove, *H* the inner case, lined below, where the fuel is in ignition with fire-clay, and above which is placed a cylindrical box or reservoir of fuel I. The space *N* between the outer and inner case is filled with sand as high as the valve *K;* the outer case is covered at the top by a lid fitting into a groove in the case *B*, into which fine sand is placed, to form a smoke-tight joint. A vessel for containing water is inserted into a groove in the lid in a similar manner. *P* is the ash-pit, *O* the ash-pit door, and *L* an aperture for a regulating valve. The fuel *F M* is introduced through the lid of the inner case *C*, also secured by a sand-groove. *G* is the grate, cast in one piece and moveable on a hinge, but kept in its position by a leg, which, when pushed back, allows the grate to fall, and discharge the whole contents of the fire-box into the ash-pit. The fuel employed is coke or anthracite coal, broken into pieces of the size of a hen's egg. In lighting the fire, some paper and dry wood, with a few house cinders, are introduced from above into the fire-box, the grate having been

FIG. 99.



previously cleared of ashes; the top is then closed and a lighted paper applied below the fire-bars. When the cinders are ignited, the ash-pit door is closed, so that the air only finds admission through the valve at *L*: the whole fire-box is then filled up with fuel by means of a funnel, which single charge lasts for twelve hours. The use of the small valve at *K* is to increase the draught when required; on drawing out the stopper, air enters, and becoming warmed by contact with the inner case, escapes to the chimney.

FIG. 100.

A regulating valve, shown in Fig. 100, is fitted to the aperture *L* of the ash-pit; it consists of a frame *G K C I* nicely balanced and turning with the slightest force upon a centre at *H;* a steelyard is attached to it at *H*, in which are several holes for the insertion of the small pin-weight *F*. This pin-weight is in fact the regulator of the quantity of air that enters the ash-pit. If it be removed altogether, the tendency of the air-current will be to force the discs *C* and *I* against the apertures to the left of them in the drawing, when no air will be admitted. If the weight is placed as shown in the drawing, a certain quantity of air only can enter, and on the draught of the chimney increasing, *C* and *I* being forced to the left, will immediately lessen the aperture and check the draught. *D* is a screw-nut for balancing the valve, *E* a cap for adjusting it without removing it from its position.

In these stoves, which burn very little fuel and in which the combustion proceeds very slowly, there is some fear of carbonic acid, on account of its great density, finding its way into the room from the ash-pit door. Dr. Ure states that this invariably occurs when the body of the stove is not heated above 250° to 300° F. Although the common fault of stoves consists in a wasteful consumption of fuel with a tendency to overheat the air, an error may be committed in the opposite direction by a too languid combustion, when the chief product is carbonic oxide, which, passing to the chimney unconsumed, involves a loss of a great part of the heating power of the fuel.

American stoves.—In a great part of the United States the fuel employed for heating apartments is anthracite, which does not

burn freely in an open grate, in consequence of the cooling action exerted by the large quantity of air necessarily admitted to the fuel. The conditions required for burning anthracite are a close grate, to which there is only a very limited supply of air brought in contact with the burning fuel with a considerable velocity. So liable is an anthracite fire to be extinguished by sudden cooling, that it is found more advisable to feed the fire from above than from the side, by a fire-door, as is usual in other stoves, and in consequence of this, the grates require to be of a peculiar construction, capable of being agitated or moved from the outside, so as to free them from clinkers and ashes. In Nott's stoves the grate-bars are curved, so as to form together three parts of a cylinder, and firmly attached to side-plates, so that the whole grate can be moved by a handle outside the stove, round an axis to which the side-plates are fixed. One-third of the convex surface of the grate-cylinder is required as a support for the fuel; by means of the handle the other two-thirds can be alternately brought to occupy its position, and by this rotating motion the ashes are caused to fall through the bars.

In Spoor's stove, also much used in America, the hot gases are made to traverse the sides of the stove in an upward and downward direction before escaping into the chimney, and the grate is of the usual circular form, but capable of being turned on a centre by a bent rod from the outside; by the motion thus communicated the ashes are removed. Olney's stove, shown in Figs. 101 and 102,

FIG. 101.

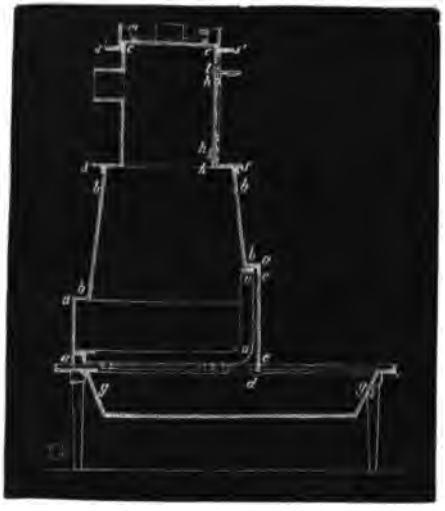


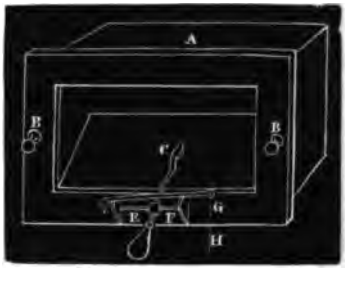
FIG. 102.

resembles in general outline that of Nott, with the exception of the escape for the gases being confined to one aperture, while in Nott's there are two, at different elevations above the grate. The grate is fixed, the bars being bent at a right angle, as shown in Fig. 103, and placed parallel with each other form the bottom and front of the grate. Fig. 102 shows a front view of the stove, and Fig. 101 a lateral section. The stove is constructed in three compartments, one above the other; the lowest, *a a a a*, is lined with brick, and contains the grate, the bars rising in front to about ⅓rd of the height of the second compartment, *b b b b*. The front grate bars are shut in by an iron door *e e*, which can be lowered so as to lie flat on the covering to the ash-pit *g g*, by a kind of hinge at *d*. The middle chamber tapers slightly towards the top, and supports the upper compartment *h h h h*. Fuel is introduced through a side door, *h h*, (Fig. 101), while the smoke and heated gases escape by the pipe *s''*. The ash-pit *g g* is in the form of a drawer, which slides in and out. The top of the stove *m m* is also moveable, and a vessel containing water is usually placed upon it. The grate is cleared in this stove in the usual manner, by means of an iron rod.

FIG. 103.

In some stoves the heating surface is surrounded by an outer casing, open at the top and bottom, through which the air of the chamber or air from the outside is caused to circulate and become warmed in its ascent. In others the smoke-pipe is constructed to ascend and descend several times, each bend being surrounded by an open casing of this kind, by which means a very rapid current of air round the heated surface is produced, and the smoke more perfectly cooled, while the same amount of radiant heat is evolved. When the air circulating through these outer casings is supplied from without, and the fireplace of the stove is also on the outside of the apartment, the current thus produced will ventilate the room, provided some means of escape is afforded for the warmed and vitiated air, either into the open air or, by means of a valve, into the chimney. The valves invented by Dr. Arnott are well adapted for ventilating such apartments. They consist of a box *A*, Fig. 104, let into the wall, just

FIG. 104.



below the ceiling and opposite the chimney flue, into which an opening is made, corresponding with that in the box; *C* is the valve, accurately balanced by a projecting weight, moving on a hinge at *E F* and fitted to the aperture in the box, in such a manner that the slightest downward current of smoke from the chimney will at once shut the valve, while the warm current of vitiated air, pressing it inwards, escapes without difficulty into the chimney. *H* is a string attached to a spring lever at *G*, by means of which the valve can be permanently closed.

A metal stove constructed upon this principle is shown in Figs. 105 and 106. The fireplace being intended to consume coal or anthracite, is constructed of bricks; the smoke and heated gases ascending immediately above the fire in a single flue, descend again through several, as indicated by the arrows, and pass off through a common flue under the floor to the chimney. The air of the apartment entering at the bottom of the stove, below the fireplace, circulates round the flues, in a contrary direction to that in which the smoke is escaping, and is discharged through a wire grating surrounding the whole upper part of the stove.

FIG. 105.

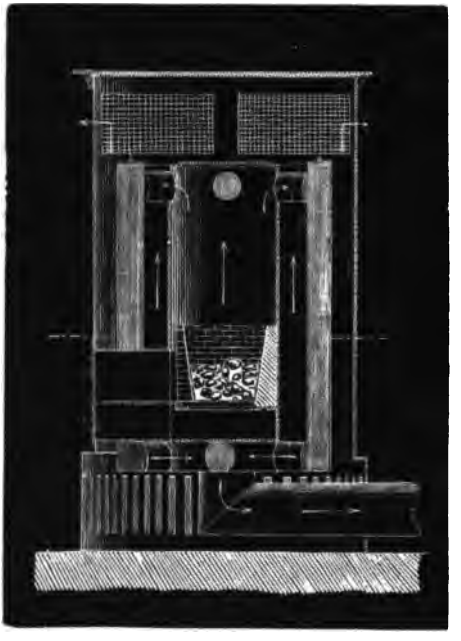
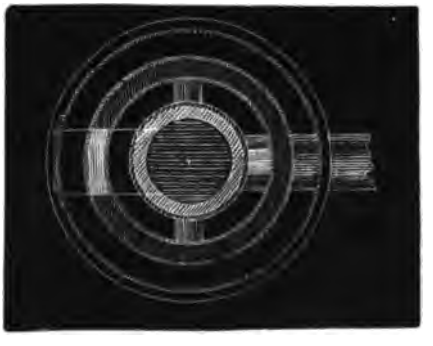


FIG. 106.



A similar arrangement is sometimes adopted with the flame reversed. The grate is then placed in the central or upper part of the stove, covered above with a perforated lid, through which the

fuel is introduced, and the air enters for supporting the combustion; the smoke traverses two concentric flues, with internal projections, in an upward direction in the one, and downward in the other, before escaping through an underground flue to the chimney; the air of the room entering below, ascends in contact with the outer concentric cylinder. The grate and smoke-flues, arranged in this manner, are speedily destroyed, and it is always necessary, before lighting the fire in the stove, to create a draught by heating the chimney.

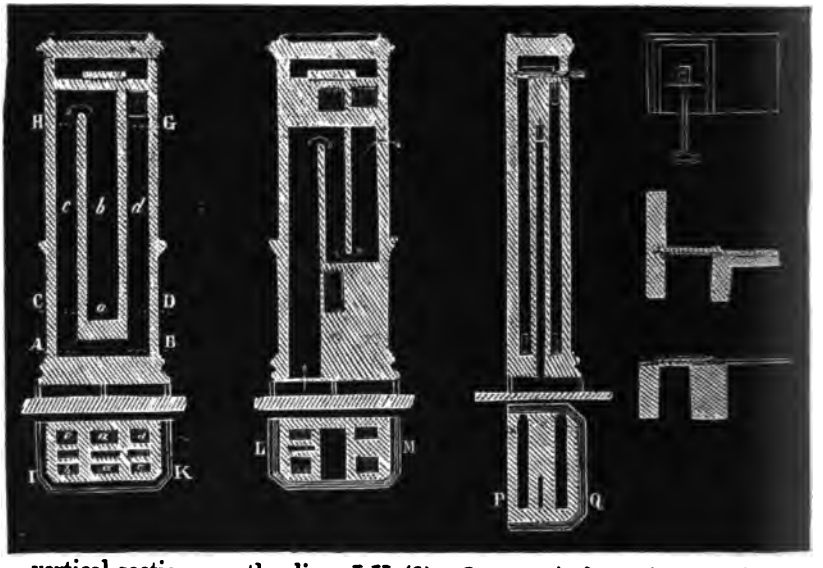
The smoke-pipe from a stove sometimes passes through a cast-iron vessel, filled with water, which becoming heated, forms a hot-water stove, retaining a moderate heat for a long time.

In order to obtain the greatest amount of heat from the flues or pipes conveying the hot gases from a stove, it is more economical to surround them on the outside with pipes for the passage of the air to be warmed, than to allow the air-pipes to traverse the flues. In the former plan the smoke is cooled more effectually, and the radiant heat, although in somewhat diminished quantity, is communicated from the inner to the outer envelope, and thence to the room; in the latter arrangement, the heat radiated to the air-pipes is almost entirely lost, passing from one side of the pipe to the other without warming the air in its passage; the air, however, being more strongly heated, the rapidity of the current is increased, which may, under some conditions, compensate for the loss of radiant heat. Much of the radiant heat may also be economized by placing solid bodies in the interior of the passages, which become heated, and communicate this heat by contact to the current of air; lateral projections in the direction of the tubes, which do not interrupt the passage of the air, are best adapted for this purpose. The smoke-pipe from a stove should always ascend for some distance above the fire, in order to secure a draught; it should never be subdivided in its upward course, as a slightly stronger upward draught in one of the passages will cause a downward current in the others. When the current has a downward direction this cannot occur, and the smoke will traverse a number of flues simultaneously.

In many continental countries, iron stoves of simple construction are still very generally used. Sometimes an iron stove is surmounted by a series of clay flues, through which the smoke and heated gases pass, a portion of their heat being stored up by the body of the clay, and afterwards communicated slowly to the

surrounding air. In other cases, the whole body of the stove is constructed of clay and frequently encased with porcelain tiles, forming an ornamental structure in the room. The fire-door is often placed in the corridor, when air from the room not being required to supply the oxygen for combustion, no draught is occasioned, and the air being stagnant, soon becomes vitiated, unless some special means for ventilating the room is introduced. A current of air is sometimes allowed to circulate through channels running parallel to the flues entering below and passing out warmed at the top of the stove. A stove of this description is shown in Fig. 107, where 1 represents a

FIG. 107.



vertical section on the line *I K* (2); 3 a vertical section in the direction of *L M* (4); 5 a vertical section in the direction of *P Q* (6); 2, 4 and 6 are horizontal sections in the direction of the planes *H G*, *C D* and *A B* (1); 7, 8 and 9, represent the details connected with the damper. The air-channel and the direction in which the air travels, is shown in 3; on each side of this channel, the smoke-flues *b c d* convey the hot gases from the fire at *a*, which, after traversing the body of the stove as indicated in 1, unite at the top before entering the chimney. Wood is generally burnt in these stoves, on a simple hearth, without a grate; a brisk fire is kindled with about 1½ cubic feet of

beech-, birch-, or pine-wood, which is soon consumed. When flame is extinguished and the embers are still glowing, the damper is closed above and the ash-pit and fire-door below, to prevent any further flow of cold air through the stove into the chimney; the heat accumulated in the body of the stove is then slowly given off to the air of the apartment.

Heating by means of Channels or Flues.—The method of applying heat by means of flues, which is one of the most ancient, having been used by the Romans for heating their baths, is still commonly practised in hot-houses. The hot gases and smoke produced in a grate placed at a lower level and on the outside of the space to be heated, are conducted through a system of flues under the floor, where they part with their heat and then escape by the chimney. Unfortunately, this mode of applying heat, certainly the best adapted for dwellings, can only be managed in the lowest floor of the house, and even there with difficulty. Great care must be taken to surround the lower part of the flue with rubbish or some non-conducting substance, so as to prevent any loss of heat in that direction. The position of the fire with reference to the area to be heated forms the only essential difference between this method of heating and that last described.

Heating by means of Hot Air.—When greater security, want of space, or other considerations, render it desirable to remove the stove to a distance from the apartments to be heated, the necessary quantity of air can be warmed in another part of the building, and conducted by air-flues into the different rooms.

Heating by hot air is the designation exclusively given to this method, although it applies with equal propriety to many of the others, the air being in nearly every case the medium through which the heat ultimately reaches its destination. When the supply of warmed air is abundant, and is transmitted to the apartments with a certain amount of force by machinery, no extra outlet for the vitiated air is necessary, sufficient ventilation being afforded in small rooms which are not overcrowded with inmates by the unavoidable crevices in windows and doors. Special means of ventilation must be provided for crowded apartments. With a view to economize the heat of the air which has already circulated once through the apartments, two methods have been proposed. The one consists in reconducting the air to the heating surface of the stove, and again transmitting it to the spaces to be warmed; this practice is decidedly objectionable, as the air

which has once passed through the lungs is no longer fit to support respiration. It is far better to conduct it to the ash-pit of the stove to supply oxygen to the fuel, where the higher temperature, as compared with the external atmosphere, which it still retains, will more than compensate for the lesser proportion of oxygen which is present. If 1 lb. of air-dried wood requires 5 lbs. = 123 cubic feet of air at 0° C. for combustion, and if, according to Rumford, 26 lbs. of water can be heated by it to 100° C., or $4 \times 26 = 104$ lbs. of air to 100° C., or $\frac{100 \times 104}{20} = 520$ lbs. of air to 20° C.; then the temperature of 20° (instead of 0°) at which, in this instance, the air is furnished to the fire, will correspond to a consumption of $\frac{1 \times 5}{520}$ = nearly 0.01 lb. of wood, which must consequently be saved.

This saving of 1 per cent, or something more, when the temperature exceeds 20° C. (68° F.), is too small to warrant any particular attention, and it is found judicious in practice to combine the two methods. The air, which has circulated for some time, may be allowed access to the hearth, and is replaced by air from without, the heating of which will then cost just as much as has been saved by employing the other for feeding the fire. Supposing that proper ventilation can be kept up in a room by means of doors and windows, the first method will necessarily be highly advantageous; the warm air streaming in will force out that already in the room, and thus produce a state of things in which the tendency of the external air to force its way through the crevices will cease, and all its attending disadvantages. It is quite certain that the loss occasioned by supplying the fire with cold air is counterbalanced by the advantage gained. The method of heating by hot air is not desirable for buildings in which the number of rooms heated varies from day to day, because the proper relation between the dimensions of the stove and the supply of hot air cannot be easily accommodated to meet a fluctuating demand. In other respects this method of heating is economical; one stove only is required, and the fuel is more completely consumed than if the same quantity were distributed in separate stoves; lastly, the advantage of an uniform, equable heat, proceeding from the level of the floor, fully compensates for any loss occasioned by the transit of the hot air through the flues.

Two plans are adopted in constructing these hot-air stoves. In

the one the smoke and hot gases are caused to circulate in an extensive series of metallic or stoneware flues, and the air to be warmed, supplied from the outside of the building, is conducted to the outside of these, where it absorbs heat from their surfaces and from the inner side of the case of the stove. In the other, the air to be warmed is conducted through metallic or stoneware pipes, round which the flame and smoke are allowed to play; the internal surface of the air-tubes is in this case the only source of heat. About 10 square feet of heating surface per lb. of coal consumed, is found practically to work well in both systems.

The forms of apparatus constructed by different inventors for heating the air are numerous. The following illustrations will give a general idea of this method of heating dwellings.

FIG. 108.

Fig. 108 represents a lateral section of a series of cast-iron pipes, in the form of an inverted Y, set in brickwork, parallel with each other, over a furnace. The flame from the furnace, after travelling to the end of the angular vault of pipes through the flue *A*, returns through *B*, and passes back again to the chimney through *C*. Air from the exterior is supplied to the pipes through the flues *N N*, and the heated air collects in the chamber *M*. Other pipes may be inserted with iron cement, in the position indicated by the dotted lines, when they will form a portion of the upper flues *B* and *C*. The position of the pipes in this arrangement is such, that the joints are well protected by a body of masonry, and there is little danger of smoke from the fire mixing with the current of warm air. The lower side of the pipes, immediately above the fire, is apt to be too much heated, but this can be prevented by carrying a brick arch along the hottest part of the flue, between the flame and the pipes. The effect of the apparatus is very much increased by employing pipes

that are cast with longitudinal internal and external projections, when a larger surface of metal is exposed both to the fire and the air-current.

Figs. 109, 110, 111, and 112 represent the hot-air stove of M. René Duvoir, much used in large workshops and manufactories in France. Fig. 109 is an elevation; Fig. 110, a section on the line $x\,x'$ (Fig. 112); Fig. 111, a section on the line $y\,y'$ (Fig. 112); and Fig. 112, a horizontal section on $z\,z'$ (Fig. 110).

FIG. 109.

FIG. 110.

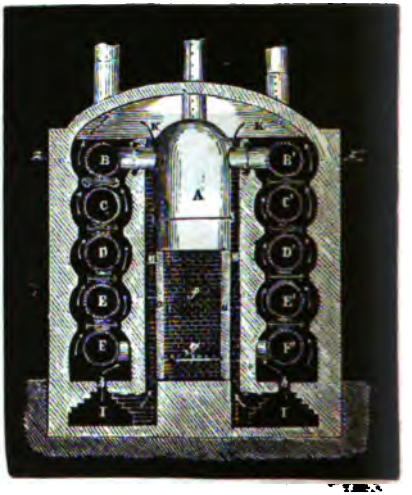


FIG. 111.

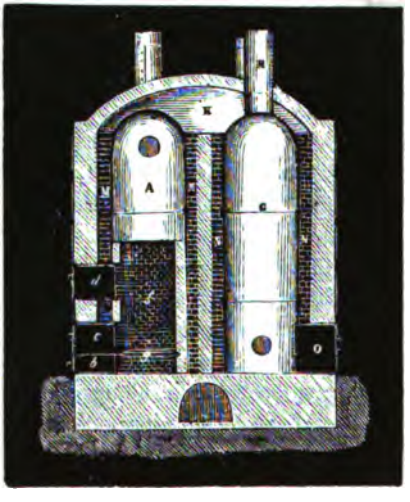
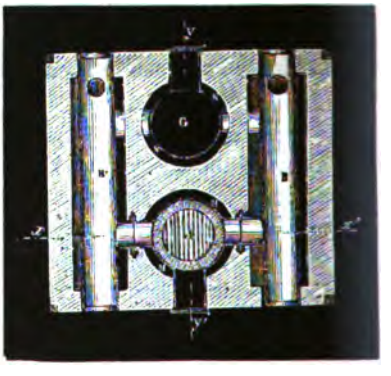


FIG. 112.



The fire is placed on a grate *g*, surrounded by a cast-iron cylinder *A*, cased with fire-bricks to a certain height. The smoke descends simultaneously through the two rows of horizontal pipes *B C D E F* and *B′ C′ D′ E′ F′*, and rises again in the cylinder *G* before passing off by the chimney *H*. The air to be heated is conducted to the stove by the subterranean flues *I I*, ascends at the sides of the two cylinders and round the pipes, collecting at the top of the stove in the chamber *K*, whence it is distributed to the different apartments. The pipes are all of cast-iron, connected together with iron cement. The upper door to the fireplace *d* is used for the supply of fuel, while *c* serves for clearing the grate. Anthracite or coke may be burned, and are indeed preferable in this stove, as they do not produce so much smoke, and the pipes require less frequent cleansing. The fire is renewed every seven or eight hours. In order to assist the draught on first lighting the fire, after the apparatus has been long out of use, a small additional fireplace is inserted in the cylinder *G*.

The hot-air stoves employed at the Chambre des Pairs and the Chambre des Députés, in Paris, were constructed by MM. Rohaut and Musard, according to the plans of M. Talabot. They have been found to answer perfectly, and have continued in action several years without requiring repair. A pair are generally

FIG. 113.

placed together, the fires being in the centre, and the chambers containing the air-pipes on each side. Fig. 113 is a vertical section of a single stove on the line *z z'* (Fig. 114). Fig. 114 is a vertical section on the line *y y'* (Fig. 113 and Fig. 115); a vertical section on an undulating plane *x x'* (Fig. 113). *A* is the fireplace, arched over at the top and perforated at *B B* for the escape of the flame and smoke, which, reverberating above and among the two upper rows of cast-iron pipe *C*, are forced by the solid brickwork, which fills up the spaces between the two lower layers, to make their escape in the direction of the arrows to an underground flue. The fireplace is about 3.3 feet long, 2 feet high, and 1 foot wide, and consumes 22 lbs. of coal per hour. The whole chamber, including the fireplace, is about 9 feet 9 inches long by 5 feet wide, and 6 feet 6 inches high. The air warmed in passing through the horizontal pipes, which are between 6 and 7 inches diameter, has no perceptible odour, very few of the pipes being so near the fire as to become red-hot even

FIG. 114.

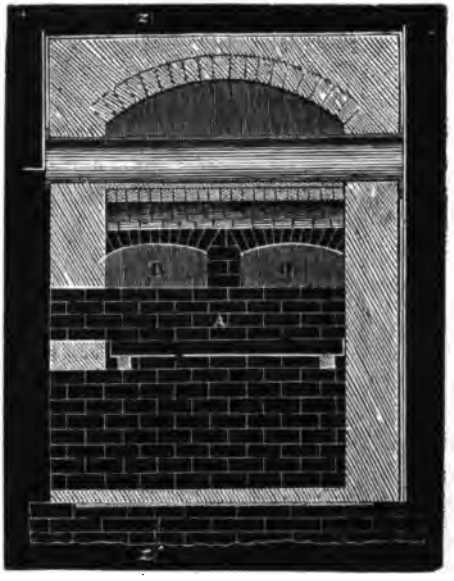
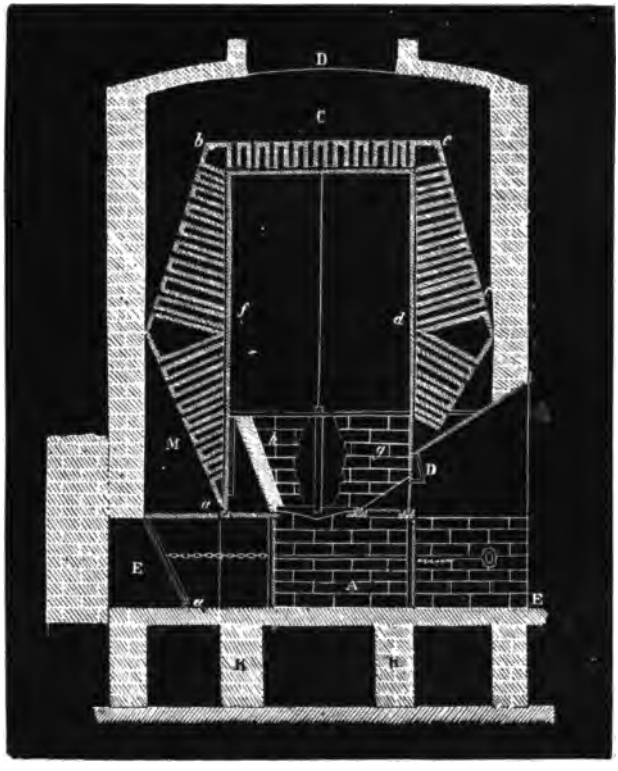


FIG. 115.

when the draught is strong. The temperature of the escaping gases is low, although the draught is good and the combustion very complete, even when the ash-pits are nearly closed. Much air finds its way through crevices in the brickwork into the chamber, and there is consequently no fear of smoke being mingled with the hot-air current. Internal ribs to the cast-iron pipes would increase the heating power of the apparatus.

A hot-air stove, similar in principle to that used in the general Derbyshire Hospital, but somewhat modified in the construction, is shown in Figs. 116 and 117. A cast-iron cylinder or cockle, closed at one end, *f*, *d*, descending as low as the grate, is inverted

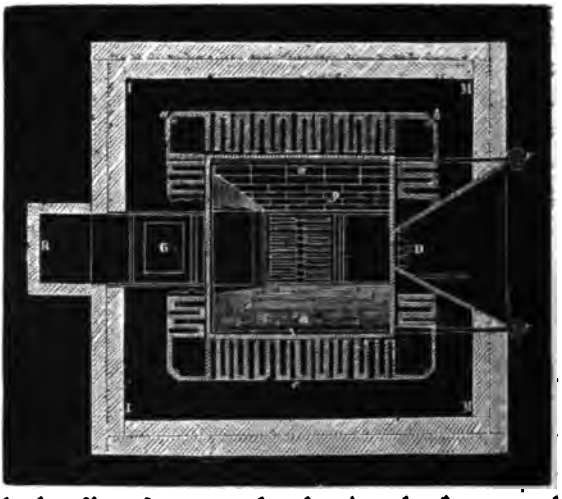
FIG. 116.



over a quadrangular fireplace in the form of a hopper, and lined with fire-bricks. Fuel is introduced through the door *D*, and the smoke escapes through two long flues running the whole length

of the furnace just above the fire at *n n*, and passing between the external brickwork and the cylinder, heats the lower part of the latter before reaching an underground flue leading to the chimney;

FIG. 117.



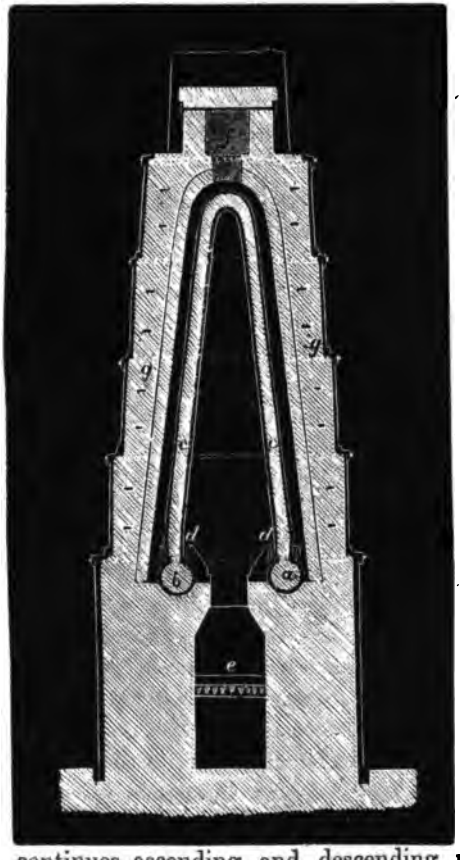
r r are the handles of scrapers for cleaning the flues *n n* when they become choked with soot. *A* is the ash-pit. Fresh air is supplied from the outside of the building by a subterranean channel passing between the walls *K K*. A revolving cowl is attached to the entrance of this channel, the mouth of which is always presented to the wind. The cast-iron cylinder, *f d*, is encased with a sheet-iron envelope, *a b c*, in which are inserted a great number of sheet-iron pipes open at both ends, and terminating within about half an inch of the cast-iron cylinder. Fresh air from between *K K* first ascends into the space *M*, enters the tubes, and coming in contact with the cylinder, is warmed, and escapes again through the upper series of tubes to the hot-air chamber, whence it is distributed over the building. These hot-air stoves cannot be economical, as little more than the radiant heat is employed in heating the air. Where only a moderate heat is required for a large body of air, the stoves with horizontal air-pipes will be found most useful; their construction is simple, they admit of being easily cleaned or repaired, and are less costly than the others. The cold air streaming simultaneously through a number of tubes, cools the smoke very effectually, and prevents the tubes from acquiring an excessive heat. A much higher temperature is

obtained with the same amount of fuel when the air-current is made to travel in an opposite direction to that of the smoke, as in the stove of René Duvoir.

The various modifications which have been adopted for raising air to a high temperature are so numerous, that we must confine our illustration to that most generally employed. Herder's "Erwärmung der Gebläseluft" and Peclet "Sur la Chaleur" contain numerous details of the mode of applying the hot blast to lead and iron smelting.

The apparatus shown in Fig. 118 consists of two horizontal pipes, *a b*, to the upper surface of which a series of U-pipes *c* are fixed, as shown in the drawing at *d*, the joints being encased in brick-work. These pipes are heated by a powerful fire *e*, the flame from which plays round the upright pipes, and passes off at *f* through a flue built on the top of the stove. The walls *g* acquire a red heat, and assist in maintaining a uniform temperature. The air is forced through the apparatus by a blowing machine driven by steam or water-power, and meeting with a stop-plate in the horizontal pipe *a*, which it enters first, the air ascends the U-pipes corresponding with this section, and passes on through the opposite pipe *b* until it encounters another stop-plate, when it re-enters another series of U-pipes, and thus continues ascending and descending until it has acquired the necessary temperature.

FIG. 118.



This plan of heating the air is certainly not economical; the air-current travels in a direction contrary to that of the smoke, through only the half of the circuit in the pipes, and the hot gases escape from the furnace at a very high temperature.

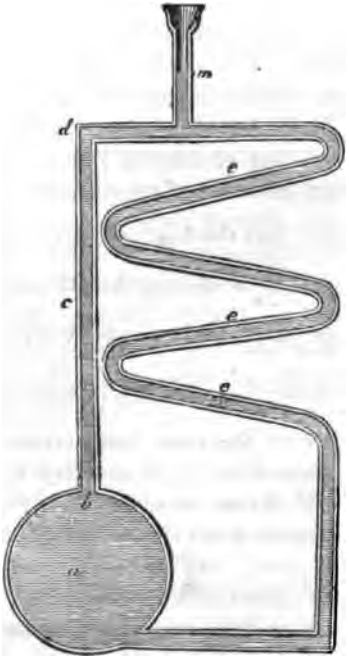
At Codnor Park Ironworks a more advantageous plan of heating the blast is adopted. Two very wide cast-iron pipes are set in a furnace in such a manner that the flames shall play first over the entire length of the one, and then in the opposite direction over the other, before escaping to the chimney; into each of these a pipe of less diameter is inserted, open at both ends, one end of which projects beyond the brickwork of the furnace. The air from the blowing cylinders is admitted into the upper narrow pipe, and passing to the far end, returns through the annular space between it and the outer pipe, is conducted thence by a short cross pipe to the annular space between the other lower pipes, and passes to the truyeres through the second pipe of small diameter. The air thus traverses in the contrary direction to the smoke, and the inner iron pipes are of great value in increasing the heating surface. The flame or heated gases from blast-furnace mouths are often made available for heating the blast.

Heating by Water and Steam.—Water and steam are frequenly employed as purveyors of heat, for which purpose they are particularly well adapted, in consequence of the high specific heat of the former and the large quantity of latent heat contained in steam. According to Delaroche and Berard, the quantities of heat contained in equal weights of water and air at the same temperature, are in the ratio of 374.6 : 100; or the heat which is liberated when water cools down 100° C., is sufficient to raise the temperature of 3.74 times as much air to the same amount. We have here, therefore, an analogous case to that of clay; the heat destined for a given quantity of air can be retained or accumulated in a much less quantity of water, and a much greater effect is produced when water, in the form of vapour, is made the purveyor of the heat. In passing into the state of vapour, water absorbs 5.5 times as much heat as is required to heat it from 0° to 100°, and this quantity of heat producing no increase of temperature in the steam, it cannot be recognised by the thermometer, but again becomes sensible when the vapour is condensed. Consequently, 1 lb. of vapour at 100° (212° F.), will, in condensing to form boiling water, give off sufficient heat to raise the temperature of 5.5 lbs. of water,

or $3.746 \times 5.5 = 20.6$ lbs. of air to 100° (212° F.), or 103 lbs. to 20° (68° F.)

When warm water is employed it must necessarily be renewed in proportion to the amount of heat required, and to avoid the trouble of constantly changing the water, a certain portion is caused to circulate in such a manner as to keep up a continuous ascending current of warm, and a descending current of cold water. Fig. 119 shows the principle of the circulation. The heat applied to the bottom of the vessel *a* is first communicated to the lower layers of water, which, becoming expanded and specifically lighter, rise to the higher parts of the vessel; they ascend to *b*, from thence into the tube *c*, and lastly to *d*. In proportion as these portions rise, however, the cold water descends in *e*, and this circulation is kept up as long as any difference of temperature exists in the different parts of the apparatus, a condition which is constantly maintained by the cooling of the water in its passage. It is obvious that *a* may be an open vessel, into which the ends of the tube dip like a syphon, but then much heat will be lost. The heat itself, in this arrangement, is the motive power for producing the circulation, which is so much the more rapid, the fewer cooling and other obstacles are placed in the way of the ascending current.

FIG. 119.



In this country, where the system of heating by water has been introduced by Perkins, closed coppers are used, which can be heated in the same manner as steam boilers; or the pipes themselves, without any boiler, are carried through a stove in numerous coils. The dimensions of the fire and the conducting pipe must be well proportioned to each other, so that the cooling takes place rapidly, and no steam is formed. To avoid all danger from explosion, which a sudden burst of

steam might possibly occasion, safety-valves are introduced; and compensating pieces, to prevent the bursting of the metal tubes by sudden expansion and contraction. The latter danger is guarded against by connecting the ends of the pipes with a stuffing-box, instead of with screws, thus combining mobility with a water-tight connection. Tubes are also provided at the top of the conducting pipes, as at *m*, for the escape of air, which is evolved from the hot water.

The quantity of water which is to be conveyed per minute from the apparatus to the space to be heated, can be determined in the following manner. If A represent the number of cubic feet of air, at a temperature of $t°$ warmer than the external air, which have to be supplied per minute; and if 1 cubic foot of water is 770 times heavier than 1 cubic foot of air, then A cubic feet of air correspond with $\frac{A}{770}$ cubic feet of water by weight; but the heat which raised the temperature of A to $t°$, is only capable of raising the $\frac{1}{4}$th part of this $\frac{A}{770}$, or, more correctly, $\frac{A}{3.746 \times 770}$, to the same temperature; in other words, $\frac{A}{3.746 \times 770}$ cubic feet of water in cooling $t°$ will raise exactly A cubic feet of air to the same temperature. But the water in the pipes has a temperature of nearly 100° C. (212° F.), and gives off from 60° to 70° of this, or cools $(T-t')°$; therefore, as much less water will be required as $(T-t')°$ is higher than $t°$, namely: $\frac{A\,t°}{3.746 \times 770\,(T-t')°} = \frac{A\,t°}{2884.4\,(T-t')°} = Q$ cubic feet $= Q$ 62.32 lbs. of water per minute. It is necessary to know the velocity with which water moves in pipes, in order to construct the conducting pipes of proper dimensions. The determination of this is the same in principle as that of the draught in chimneys, the friction of the water being somewhat different from that of the air. The velocity, together with Q, gives the diameter of the pipes, and the latter the dimensions of the fire. The ascending pipe is straight, and surrounded by badly conducting substances, to prevent cooling; the descending pipe, on the contrary, is furnished with every facility for communicating heat to the air of the room. When the heat is to be communicated to a very extensive space, the water becomes too cold in the more remote rooms, and a separate set of pipes for each half of the building is desirable.

Steam heats much more effectively than water, and consequently less of it is required. As 24.6 cubic feet of air at 0° weigh 1 lb., then A cubic feet in the former equation will weigh $\frac{A}{24.6}$ lbs., and will be heated by the condensation of $\frac{A}{24.6 \times 3.746 \times 5.5}$ lbs. of steam of 100° C. (212° F.) in forming boiling water (of 100° C.), and consequently by $\frac{A\,t^{\circ}}{24.6 \times 3.746 \times 5.5 \times 100} = Q$ lbs. of steam to t° higher than the temperature of the external air. The pipes destined to carry the steam to the place of condensation are chosen of narrow bore (about 1.5 inch), and to avoid all condensation during the transit, are surrounded with a thick covering of list or woollen cloth; the condensing pipes are of copper or cast-iron, at least four times as wide, and must be so arranged that the air can escape when the steam is first admitted, or this would otherwise very much retard its dissemination. These pipes should be rough and not polished, and the copper tubes should be painted or stained so as to give them the appearance and the properties of cast-iron. To allow for the expansion in length, the same plan may be adopted as in water-pipes, or simply a bent piece of flexible metal may be inserted into the course of the tube, which by bending to a greater or less degree, compensates for the expansion. It is extraordinary that different bodies should condense steam in a very unequal manner, according to the nature of their surfaces. Tredgold found the following quantities of steam condensed per hour by a square foot of surface of the different substances in the form of pipes exposed to a temperature of 59° F.:

Tin-plate	0.185 lbs.
Glass	0.333 ,,
New sheet-iron . . .	0.340 ,,
Rusty sheet-iron . . .	0.393 ,,

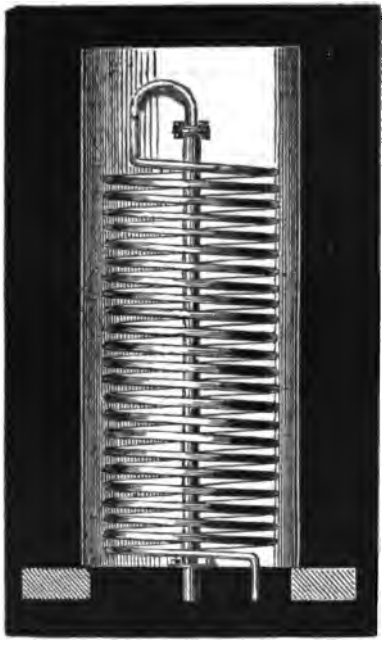
Clement further observed that at a temperature of 15° C. (59° F.) in the surrounding air, 1 square foot of surface of horizontal cast-iron pipe would condense 0.234 lbs. of vapour, of bright copper pipe 0.184 lbs., and of blackened copper pipe 0.213 lbs., which quantities are somewhat increased by a perpendicular position of the pipes.

Whatever form is given to the apparatus, ample means must be afforded for the removal of the condensed water, and a special

set of pipes, conducting it back to the boiler, are generally employed for this purpose. Occasionally a quantity of water is expressly left in the pipes after circulation has ceased, that the accumulated heat (as in clay stoves) may be obtained. In order to prevent any sudden, unexpected powerful condensation drawing up the water from the boiler, there must be a valve, opening downwards somewhere about the spot where the vapour enters the system of pipes. There is a greater loss of heat, on account of the larger dimensions of the pipes, when air is made the medium of transmission, than when either water or steam are employed, while the latter are not so well calculated to assist ventilation. When water is employed as the heating medium, the apparatus is, on the whole, simpler, the temperature more easily regulated, and not so suddenly elevated as by the use of steam; the latter, however, will convey the heat to much greater distances, and can be employed to heat the upper floors of lofty buildings, where the pressure of columns of water would prove very inconvenient.

The diameters of the condensing pipes, when steam is used, must not be too large, or the air is expelled with difficulty; nor too small, when the friction impedes the passage of the steam, and diminishes its tension. They may vary from 3 to 8 inches in diameter, and the best manner of supporting them is by iron rods fixed to the ceiling.

FIG. 120.



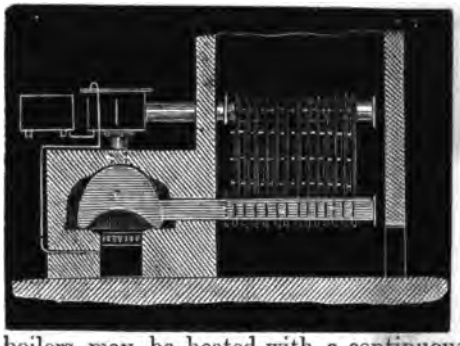
One of the best modes of employing steam is shown in Fig. 120. There is only one pipe through which the steam ascends from the boiler, and also only one extensive coil of pipe by which the condensed water returns. This arrangement is better than those in which the steam enters a number of pipes simultaneously, as it is difficult in the latter case to remove the air perfectly from all the pipes. A cock for allowing the air to escape, must

be introduced at the top of the pipe, which is not shown in the drawing. When placed in the locality to be heated, the above apparatus becomes a steam-stove. If at a distance, and surrounded with a case, through the bottom of which air enters, the warmed current of air may be transmitted to a higher position. If the diameter of the pipes is small, the length must be increased in proportion to afford a sufficient heating-surface. The pipes may be of copper or iron; the latter are cheaper and require no additional support.

It is always desirable to conduct the condensed water again to the boiler; heat is thus economized, and the incrustation of the boiler and pipes, which often proves a very serious inconvenience, is prevented.

Price's hot-water stove for heating air, which is used in many public establishments in this country, is shown in Fig. 121. The heating-surfaces are constructed of square cast-iron boxes, placed vertically, affording about 3 feet surface, and connected at two of the opposite angles with horizontal pipes. The joints are secured with collars of iron-wire gauze and red putty, which stands remarkably well. The boilers may be heated with a continuous supply of anthracite in the manner described below (*vide* Evaporation).

FIG. 121.

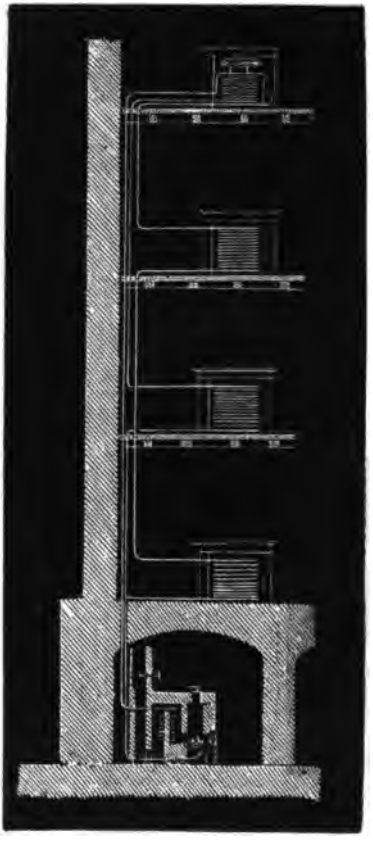


The British Museum is heated with hot water upon a somewhat different plan, invented by Mr. Perkins. The apparatus consists of a circuit of pipes of small diameter, surmounted by an hermetically closed expansion vessel; the lower portions of the circuit pass in several coils through a furnace, where the water becomes heated to a very high temperature.

Fig. 122 represents the general arrangement of one of these coils. The water ascends by a single tube from the furnace, and descends in two tubes, each of which forms two helices at different elevations. The tubes are about an inch in diameter, very thick, and capable of withstanding a pressure of 3,000 atmospheres. A force-pump is employed in filling

the tube with water, which completely expels the air and at the same time affords an opportunity of testing the strength of the apparatus up to a pressure of 200 atmospheres. The tubes are screwed together in such a manner that the somewhat tapering end of the one enters the flat metallic surface of the other.

FIG. 122.



It has been found by experience that the portion of the circuit heated by the furnace should not be much less than $\frac{1}{6}$th of the entire length. In Fig. 123 the coil of pipe is quadrangular, and so arranged in the furnace that the flame heats the one half in ascending, and the other in descending, before escaping to the chimney.

Fig. 123 and 124 represent the furnaces employed at the British Museum. Fig. 123 is a perspective view, with the front wall removed, and Fig. 124 a horizontal section. The fire is supplied with fuel from above; the smoke and hot gases pass round the entire circuit of pipe before escaping to the chimney. The temperature of the pipes in the highest part of the circuit is generally from 300° to 400° F., and in the lowest part of the descending column it does not exceed 140° to 160° F., which temperatures correspond to pressures of from 4 to 15 atmospheres. In the furnace, however, the pipes are heated to low redness, and if the water acquired that temperature, which is calculated at 932° F., the pressure would amount to 857 atmospheres.

Notwithstanding every precaution, there is a constant loss of a small quantity of water, even when no perceptible leakage can be discovered; and in extensive coils it is necessary to add about a pint of water every eight or ten days.

The total extent of circuit is seldom allowed to exceed 400 to

FIG. 123.

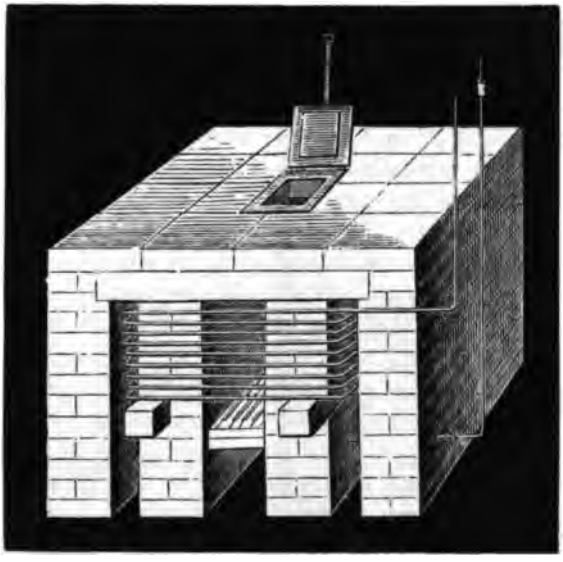
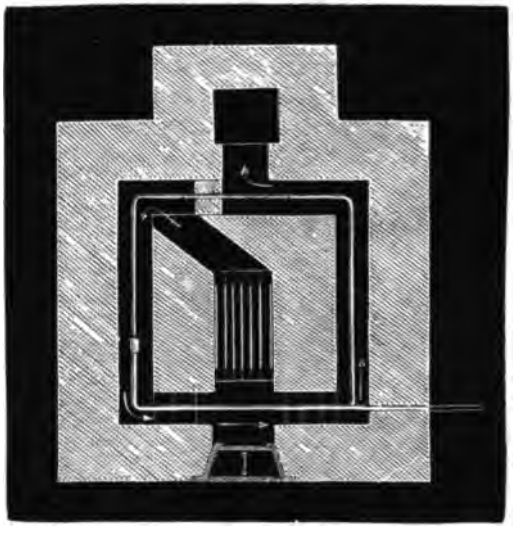


FIG. 124.



500 feet, and 2 feet in length is considered sufficient heating surface for 100 cubic feet of space.

A very admirable system of heating and ventilating by hot water has been adopted in many of the public buildings of France on the recommendation of committees, consisting of the most eminent scientific men of the day, and carried out by very able engineers. As one illustration of the system, which is modified according to circumstances, we select from the numerous plans described by Peclet in his "Nouveaux documents relatifs au chauffage et à la ventilation des établissements publics," that which has been adopted at the new prison Mazas. This building is constructed for the solitary confinement of prisoners, whose health and comfort, as far as they are dependent upon warmth and pure air, have certainly been considered with the greatest attention, and in a manner worthy of imitation by governmental boards in this country.

The prison consists of six long stacks of building, each of which is two stories high, radiating from a common centre. The middle of each of these is occupied by a long corridor, extending from the ground floor to the roof, and terminated by a large window. On either side is a range of cells, the capacity of each being about 700 cubic feet. Upon the system of M. Grouvelle, to whom the heating and ventilation of the building was intrusted, the air supplied to the cells is heated by contact with pipes containing hot water, which are in connection with reservoirs on each floor, where the water is heated by a coil of steam pipes supplied from generators in the basement of the central building. Ventilation is produced by a vast chimney about 40 square feet in section, and nearly 100 feet high, which is also situated in the centre of the edifice. The whole of the air from the cells is drawn by the action of this chimney in a downward direction through a vertical pipe in each cell, which being in connection with a night-stool, serves at the same time for removing excrementitious matters; the pipes from the several cells terminate in an underground vault, whence the vitiated air is drawn off by the chimney draught, while the solid and liquid excrements are collected in barrels, to be removed at fixed intervals. A balcony extends along each corridor at the height of the first and second stories, on to which the cell doors open. Channels are carried below these balconies in which two sets of cast-iron pipes convey currents of hot water in opposite directions, by which means a uniformity of temperature is established throughout the entire circuit. On the ground floor this channel is below the floor in front of the cell doors. The channel

is intersected by partitions corresponding with the walls of each cell, and the air from the corridor is admitted to the spaces between these partitions by gratings, and thence after coming into contact with a considerable surface of pipe is admitted through several apertures to the interior of the cells.

FIG. 125.

Fig. 125 is a vertical section of one of the buildings, on a plane parallel to the axis, and in part through the middle of one of the side balconies. *A* is the large wrought-iron reservoir, in which the water is heated by a coil of steam pipes supplied from the underground generators; *C C* are vessels in connection with the systems of pipes to afford space for the expansion of the water. *D D* the pipes for conveying the fecal matters and vitiated air from the cells. *D' D'* apertures for admitting the air of the corridor to the channels containing the hot-water pipes. *D'' D''* apertures for the air to enter the channels situated below the ground floor. *E E* apertures connecting the channel with the interior of the cells. On leaving the reservoir the hot water traverses the single pipe, shown in Fig. 125; but on arriving under the first cell, a branch pipe conducts

a portion to the opposite side of the corridor, so that hot water is flowing simultaneously through pipes on both sides, and the cooled water returning in the same manner to the bottom of the reservoir.

Fig. 126 shows a vertical section of one of the cellular buildings

FIG. 126.

at right angles to the axis. Each cell is rather more than 12 feet long, about 6 feet 6 inches wide, and nearly 10 feet high; each contains a gas-burner and a night-stool *C*, the descending-pipe from which carries the vitiated air of the apartment into the vault below, which is in communication at the one extremity with the ventilating chimney, and closed by a double door at the other which is only occasionally used for removing the barrels. The air escapes between the lid and the seat of the stool from the cells,

and through the short appendages on the pipes into the vault; the longer extremity of the pipe dips into the close barrel; the air aperture can be stopped by a cap and some hay. *A B* are the hot-water pipes, extending the whole length of the building below the galleries, enclosed in a plastered channel to which the air of the corridor has access, and passes warmed into the cells through the apertures *D*, which can be closed by plates of cast-iron. *E* windows of the cells; these are now never opened, in consequence of the great irregularity in the ventilation, which resulted from the effects of wind and sun. *F* is the grated window at the end of the corridor. *G* expansion-vessels.

According to the report of a committee upon the whole system of heating and ventilation, the chimney is capable of drawing 1,059,300 cubic feet of air per hour, which as there are 1,200 cells altogether, is equivalent to 882.7 cubic feet of air per cell per hour, or more than double the quantity required; very careful experiments having proved that 353 cubic feet per hour was amply sufficient to remove all noxious effluvia and establish a thorough current down the ventilating pipes. By means of registers in the subterranean air-vaults, the ventilation can be rendered uniform in all the six ranges of building. The quantity of air actually supplied averaged, during several months, between 529 and 882 cubic feet for each cell in the hour. A temperature of 55° to 61° F. was maintained during winter in all the inhabited parts of the building, and the apparatus was capable of affording more heat if required, only four of the six steam generators having been employed. For the seven months during which artificial heat was required, the mean temperature of Paris being about 43° F. and assuming the interior of the building to have a mean temperature of 57° F., the consumption of coal for the production of the difference in temperature of 14° F. was, on an average, 5¼ cwts. a day for each of the six stacks of building, and 2 cwts. for the general offices of the prison. The total consumption was therefore $5\frac{1}{4} \times 6 + 2 = 33\frac{1}{2}$ cwts. a day.

For producing the ventilation, the mean consumption of fuel was in summer 8 cwts., and in winter 7 cwts. a day; but for obtaining a ventilation of 1,059,300 cubic feet per hour, the consumption of coal in winter was 44 lbs., and in summer 55 lbs. per hour.

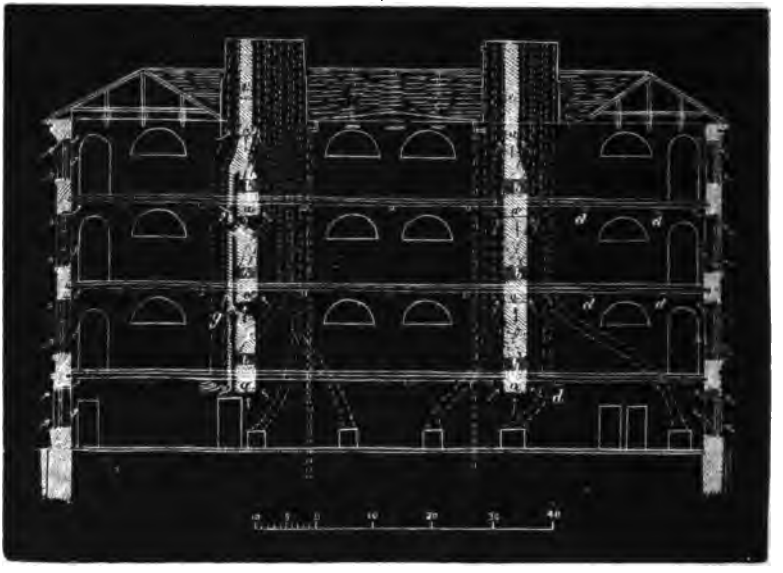
In the year 1852, a committee, appointed by the managers of the Infirmary at Newcastle-upon-Tyne, inspected the principal hos-

pitals, both in London and the provinces, with a view to ascertain the best practical method of warming and ventilating such institutions. So universal was the support given to the open fire for heat, and the window for admitting air, that the committee, after mature consideration, agreed to adopt this plan as being more healthy, cheerful, and under better control. The execution was entrusted to Mr. Dobson, architect, who has kindly favoured us with the following drawings and description of the plans carried out by him, which have been eminently successful.

The wards are double, each of them 106 feet by 23 feet, and 13 feet 6 inches in height; they are divided by a wall, in which are the open fireplaces, ventilators, &c. This wall is perforated with large circular openings, to allow a free communication for the air from window to window, which can be regulated according to the direction of the wind.

The admission of cold air into buildings of this nature requires great care, as the slightest draught upon the patients would be productive of the worst consequences; it should be distributed as much as possible over the whole room. This effect is attained by forming each window into a kind of louvre. When open, as shown in Fig. 127, the sash is at an angle of inclination, causing

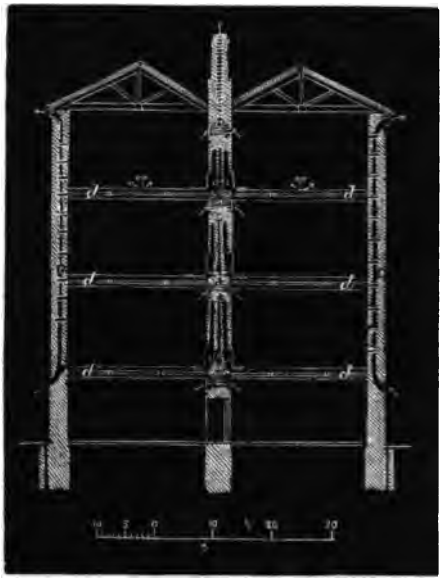
FIG. 127.



the cold air to enter above the heads of the patients, as indicated by the arrows, no beds being placed immediately under the windows.

Cold air is also admitted to the centre of the rooms at the table foot, as shown upon the upper floor in Fig. 128, at a sufficient distance from the beds to produce no inconvenience. The outside walls are built hollow, having an air-vent *c*, 3 inches wide, communicating with the atmosphere by air-holes at the top and bottom. A current of air is thus established, which prevents the deposition of moisture on the walls. From this vent the cold air is conveyed by an air-channel *d*, formed along the ceiling by the bearers or beams which carry the floor, and admitted at the table leg, where there is a valve which can be closed at pleasure.

FIG. 128.



The contaminated air is removed from the several wards by exhaustion, on a very simple plan, as shown in the engraving. The fireplaces are placed back to back, having a malleable iron air-chamber between them, protected from the action of the fire by fire-clay lining. It is perforated at the top and bottom, to allow the atmosphere, which is supplied to it from the room below, to become heated and pass off by the ventilating flue *c* (the dotted lines in Fig. 127 are smoke-flues). Thus the heat of the fire in the ward above is made to ventilate the one below. The uppermost ward is ventilated upon the same plan, although there is of course no fire-place above it; the ventilating flue, receiving additional heat at each story, becomes sufficiently warmed to draw the vitiated air from the uppermost. The power of the ventilating flue is increased by burning a jet of gas on either side of the iron chamber, which jets are shown in all the ventilators, Fig. 128, and

are intended to assist the ventilation in summer, or when the different fires are not burning, as well as in lighting the wards.

Advantage is also taken of the heat of the smoke from the fires of the bake-, brew-, and boiler-houses, which is conducted along insulated iron cylinders encased with brick. The smoke from these cylinders is conveyed into one flue *g*, while the heated air is conveyed into the ventilating flue *e*. The heat generated from these flues is of course very great, and from recent trial, has been found so powerful, that the architect intends to make use of the superfluous warm air to supply additional heat to the wards when required.

The extreme simplicity of this method, and the extraordinary ventilating power obtained, render it in every way adapted to heating or ventilating an infirmary, or large rooms where numbers of people assemble.

For churches, theatres, and indeed all rooms where large numbers of persons are constantly congregated together, a thorough supply of pure, fresh, but at the same time genial air, is an object of the greatest consequence, although, until lately, it has had little attention. Our churches are, for the most part, filled with roasted or over-heated air, the upper parts of our theatres cannot be endured by persons of delicate constitution, and even the Houses of Parliament have formed no exception to the general rule of imperfect ventilation. The inconveniences attending the want of proper ventilation are, however, beginning to excite public attention, and numerous plans and experiments have been undertaken to effect this in the most complete and economical manner. The plan adopted for the Infirmary at Newcastle is one only of many others which have been tried with variable success. The problem to be solved is the economical supply of an adequate quantity of pure and properly warmed air to a certain area in a given space of time; the amount of air constituting this supply, varying of course with each individual case. It appears that philosophers are not agreed at present upon the mean quantity of air required by a number of individuals during a given time, and until this point has been definitively settled, the calculations which must obviously be based upon it will necessarily differ according to the standard assumed by each observer. There can be no doubt, however, that it is preferable in the meantime, until that question shall receive a definite answer, to supply an excess of fresh air rather than suffer from a deficiency, which latter has been the prevalent error in practice.

In the House of Commons, which has been warmed and ventilated under the superintendence and according to the plans of Dr. Reid, the air is supplied from Old Palace Yard to the basement of the building: passing first through a fibrous veil 42 feet long by 18 feet 6 inches deep for the exclusion of visible soot, it arrives at the heating apparatus, consisting of large chambers intersected by steam pipes, and proceeds from thence to other chambers, where it can be mixed with cold air and brought to any required temperature. The floor of the house is double, and the space below the floor can be connected by means of valves with the hot-air chamber. The floor is perforated by a great number of apertures, and these are covered with hair-cloth, so that the hot air in escaping from the floor into the body of the house is well diffused, and no perceptible current is experienced. Having performed its functions, the vitiated air ascends to the ceiling, which is also double and perforated, in the same manner as the floor, whence it is carried off by the draught created by a powerful fire under a chimney shaft erected in another part of the building.

The plan adopted by Mr. Barry for warming and ventilating the House of Peers, the royal ante-chamber and the public lobby, differs from that just described both as respects the admission of the air and its removal. The floors of the rooms are not perforated, and are heated in the first instance simply by the passage of hot air below them; the hot air then escapes by passages along the external sides of the rooms to the ceiling, which is divided into two compartments, the one for the admission of the warm air, entering at the sides, and the other for the exit of the vitiated air. The warm air after passing below the floor to the roof becomes somewhat cooled, so that its temperature on entering the ceiling is a few degrees lower than that actually present in the room; it consequently descends to the level at which it is at once heated again, and, deteriorated by combustion, respiration, &c., rises through the centre of the room, passing through the ceiling to a foul-air chamber above, whence it is conducted to a chimney and carried off by the peculiar motive power first suggested by Dr. Richardson to the production of draught. This power consists of a jet of steam, which when produced under pressure of 32 lbs. to the square inch is capable of setting 217 times its bulk of air in motion; 10,000 cubic feet of air are thus gradually diffused through the three apartments per minute, no draught of any kind is perceptible, and no inconvenience is experienced from dust or

other solid particles being carried mechanically forward by the air, as is said to be the case when the air enters from the floor.

In other large buildings, as at the prison in Milbank, warm air is admitted at the ceiling, and carried off by the draught of a chimney in connection with the sides or lower part of the rooms. At the Reform Club House, at the new Hospital for Consumptive Patients at Brompton, warm or cold air is forced forward by a fan or pumped into channels conveying it over the whole building by a steam engine in the basement, and allowed to find its escape through chimneys and other apertures. Although it is not probable that the same arrangements can be adopted for heating and ventilating all extensive buildings, differing in construction and in the uses to which they are applied, yet it is to be hoped that the various experiments which are now being tried upon a large scale may lead to a sound knowledge of the fundamental principles to be observed for securing an object so conducive to health and comfort.

The extent to which the air is vitiated by respiration, transpiration, and the combustion of illuminating materials, is estimated by Peclet as follows:

The respiration of an individual has been ascertained to vitiate nearly 12 cubic feet of air per hour. The water exhaled by the lungs and skin amounts to 589 grains (0.084 lbs.) in the same time; and supposing the air to be at a temperature of 59° F., and to take up about half of the quantity of moisture it is capable of sustaining at that temperature, which is about the average quantity it does take up, there will be required in round numbers per individual per hour, 212 cubic feet of air, to remove all the exhalations from the skin and lungs.

The substances employed for giving light require oxygen from the air in proportion to the amount consumed, and if $\frac{1}{5}$ of the oxygen contained in the air be the quantity abstracted by the combustion, candles of 6 to the lb. will each require about 10 cubic feet, wax candles about the same quantity, and oil or lamps with large burners about 40 cubic feet per hour.

The quantity of carbon consumed in the process of respiration amounts to about 155 grains per hour, which quantity, calculated upon the principle laid down in the former chapters, would afford 73 units of heat; but a large portion of this heat is required to retain the moisture exhaled, amounting, as stated above, to 589 grains, in a state of vapour, and is not available as sensible heat:

the quantity is thus reduced to 48 units of heat, which would be in itself sufficient to heat the amount of air required for respiration to a proper temperature, if the heat so communicated were not dissipated by transmission through the walls and windows of dwellings. The loss of heat from these sources has been estimated for a difference of temperature of 36° F. between the external and internal air, and an intermittent system of heating, at about 7 units of heat per hour per square foot, for walls of 1 foot thickness, and at about 8 units for every square foot of glass window surface. From these data, an approximate estimate may be made of the amount of air to be supplied in each case of practical application, and of the amount of heat required to be communicated to it under different circumstances.

Professor Thomson has thrown out the idea that air may be heated for warming and ventilating dwellings by mechanical agency solely, as by a water-wheel or with the aid of a less quantity of fuel in a steam-engine, than could be made to produce the same amount of heat in a direct manner. On the general principles of the dynamical theory of heat, he states, "That it is mathematically demonstrable, that any substance may be heated 30° (Fahr.) above the atmospheric temperature by means of a properly contrived machine driven by an agent spending not more than $\frac{1}{3\frac{1}{3}}$ of energy of the heat communicated; and that a corresponding machine, or the same machine worked backwards, may be employed to produce cooling effects requiring about the same expenditure of energy in working it to cool the same substance through a similar range of temperature. When a body is heated by such means about $\frac{3}{3\frac{1}{3}}$ths of the heat is drawn from surrounding objects, and $\frac{1}{3\frac{1}{3}}$th is created by the action of the agent; and when a body is cooled by the corresponding process, the whole heat abstracted from it, together with a quantity created by the agent, equal to about $\frac{1}{3\frac{1}{3}}$th of this amount, is given out to the surrounding objects." As no such method of heating air has yet been practically employed, we must refer the reader for the theoretical details on this very interesting topic, to the Professor's paper in the Phil. Mag. for February, 1854.

Application of Fuel to Vapourization. — Fuel is used most extensively for the conversion of liquids into vapour. The heat produced by the combustion of the fuel is then communicated to the liquid, through the medium of a metallic vessel, or sometimes the current of heated gases is carried rapidly over the

surface of the liquid to be vapourized. In the first the material of the vessel and its thickness might be supposed materially to affect the transmission of the heat, but this is not found practically to be the case. The material and thickness of the metallic vessels through which heat is communicated to a liquid, by a current of heated gas or by direct radiation, is found to exert so little influence upon the amount of vapour produced, that it may be entirely neglected as far as the production of vapour is concerned.

Various methods are adopted in converting liquids into vapour according to the object in view, although the manner of applying the fuel differs but little in principle.

1. Vapour is produced for its motive power and as a purveyor of heat, and the operation may then be distinguished as *Vapourization.*

2. The object may be to separate by vapourization and collect by condensation, a more volatile from a less volatile liquid, and the process is then called *Distillation.*

3. The simple removal of a volatile liquid from one less volatile or fixed, is called *Evaporation.*

4. When the liquid that moistens a solid, is removed by evaporation, the process is called *Desiccation* or *Drying.*

Vapourization.—It is beyond the limits of the present work to enter upon a description of the form, dimensions, thickness, or other particulars connected with the boilers employed for the purposes of raising steam of different degrees of pressure; we confine ourselves to a few illustrations of the usual and most approved arrangements adopted for applying the fuel required to raise steam.

The furnace is placed either below the boiler or in a separate cylinder within it, so as to be completely surrounded by the surface containing the liquid, and the hot gases are conducted to the chimney by a flue or series of flues, which are brought more or less into contact with the external surface of the boiler, so as to be cooled down to a temperature of about (300° C.) 550 to 600° F., which corresponds to the maximum amount of draught in the chimney. The grate is generally constructed of wedge-shaped bars of cast-iron, the broad part of the wedge being placed uppermost. The extent of grate-surface is regulated by the amount of work to be done, the size of the boiler, and the kind of fuel to be employed. It is not possible to give any very exact dimensions to be observed in its construction, nor is it of very great importance, as the

amount of fuel consumed can be regulated by dampers applied to the flues or chimney. The usual dimensions, when coal is used as fuel, are 1 square foot of grate surface for a consumption of 20 lbs. of coal per hour. Tredgold recommends about a square foot of grate surface for every horse-power of vapour required, which, estimating the coal consumed at 11 lbs. per horse-power, would very much increase the size of the grate.

The following relations between fuel consumed, grate surface, and heating surface, are given by Mr. Prideaux in an admirable little work on the economy of fuel, in which he advocates the use of compressed air, to increase the heat of furnaces.

Fuel burnt per hour per square foot of fire-grate:

In Cornish engines	3½ to 4 lbs.
In factory and marine engines	10 to 16 „
In locomotives	80 to 100 „

The number of square feet of heating-surface in boiler, required to evaporate 1 cubic foot of water per hour, is:

In Cornish boilers	70 sq. ft.
In factory and marine boilers	9 to 11 „
In locomotives	6 lbs. „

The number of square feet of heating surface to each square foot of fire-grate, is:

In Cornish boilers	40 sq. ft.
In factory and marine boilers	13 to 15 „
In locomotives	50 to 70 „

The boiler should in all cases be at a considerable distance from the flame. If it be placed too near, as is very frequently the case, the flame may be extinguished, or much smoke and imperfect combustion produced by the cooling effect of the boiler and its contents, which are always at a temperature greatly below that of the flame. A distance of 14 to 16 inches from the grate to the bottom of the boiler has been considered sufficient when coal is the fuel, 30 inches for wood, 20 for turf, and 24 for coke, but in most cases they may probably be increased with advantage to ensure complete combustion of the gases before they come into contact with the surfaces to be heated.

The advantage of flues in bringing the heated gases into contact with the sides of the boiler was disputed by many engineers for a

considerable time, and the whole value of the fuel was attributed to the radiant heat it afforded; but this erroneous view has been since disproved, and arose from the fact of far too large a quantity of air being admitted to the fuel, which cooled the products of combustion to such an extent as to render them nearly valueless as sources of heat.

With a view to test this opinion in a practical manner, a commission of the Industrial Society of the Grand Duchy of Hesse experimented upon the relative effect produced by a different arrangement of the furnace and flues in relation to the boiler, with different kinds of fuel, the same boiler being employed in all the experiments, while the furnace was differently arranged in each case.

The following arrangements were tried:

A. No flues were constructed, but the boiler was freely suspended above the fire.

B. The bottom of the boiler was alone exposed to the radiant heat of the fire, and the heated gases circulated once round the boiler in a flue which commanded the entire height of the sides of the boiler.

C. The bottom of the boiler was exposed to the radiant heat, but the heated air circulated twice round the sides of the boiler, the flue being only one-half as high as in experiment *B.*

D. The fire was arched over, leaving an aperture in the centre of the arch, through which the hot gases impinged upon the bottom of the boiler, and circulated freely and simultaneously round the sides in an annular space before escaping to the chimney through several apertures at the sides.

E. The bottom of the boiler was heated by direct radiation, and the heated air traversed the sides of the boiler in two flues, one on either side, which joined again above the fire, and each of which was consequently only the half of the circumference of the boiler in length.

F. The bottom was heated by radiation, and the hot gases traversed simultaneously two flues placed on either side, and each making the complete circuit of the boiler.

The following table contains the results of the experiments; the figures indicating the quantities of fuel employed for producing a similar effect in the same space of time; the highest corresponding with the most defective plan.

Wood . {	*F.*	*E.*	*C.*	*B.*	*D.*	*A.*
	63	68·8	68·9	72·19	72·23	100
Turf . {	*F.*	*C.*	*D.*	*E.*	*B.*	*A.*
	53	66	71	72	76	100
Coal . {	*C.*	*F.*	*B.*	*F.*	*D.*	*A.*
	73	73	83	85	91	100

The result of these experiments clearly shows, in the first place, the advantage of allowing the hot gases to circulate in flues round the boiler; secondly, that with suitable flues, the saving of fuel is much greater when turf and wood are employed than is the case with coal; in the case of turf, nearly the same effect being produced with ⅓ the quantity, ⅓rd being saved in the case of wood, and ¼th only in that of coal. It further appears that two flues are more effective than one, and the arrangements indicated in experiments *E* and *F* are generally the most beneficial. The arrangement adopted in experiment *D* does not appear to have had a fair trial. If the arch were employed in conjunction with a system of flues, it is probable the effect would have been greatly increased. Coal radiates much more heat than either wood or turf, and the gases are consequently less heated, which accounts for the diminished action of the flues, while any great depth of fuel not being adapted to the consumption of coal, a much larger quantity of air generally passes through the grate and furnace than is required for its complete combustion, and this of course tends to diminish the temperature of the gaseous products.

The arrangement of the furnace which is generally adopted in this country, and considered the most economical, is that in which the furnace is surrounded by the boiler, as shown in Fig. 129. This is the construction adopted in the large boilers employed at the Cornish mines, which are celebrated for the large amount of work performed at a small cost of fuel. The outer cylinder is of very large dimensions, being often 6 feet in diameter and 60 feet long. The hot gases, after passing through the centre of the boiler, return through the flues *o o*

FIG. 129.

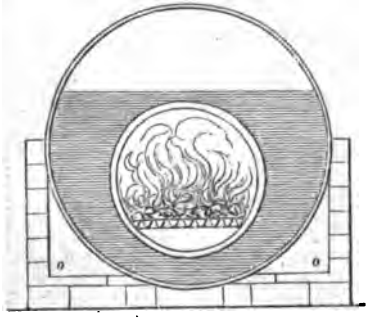
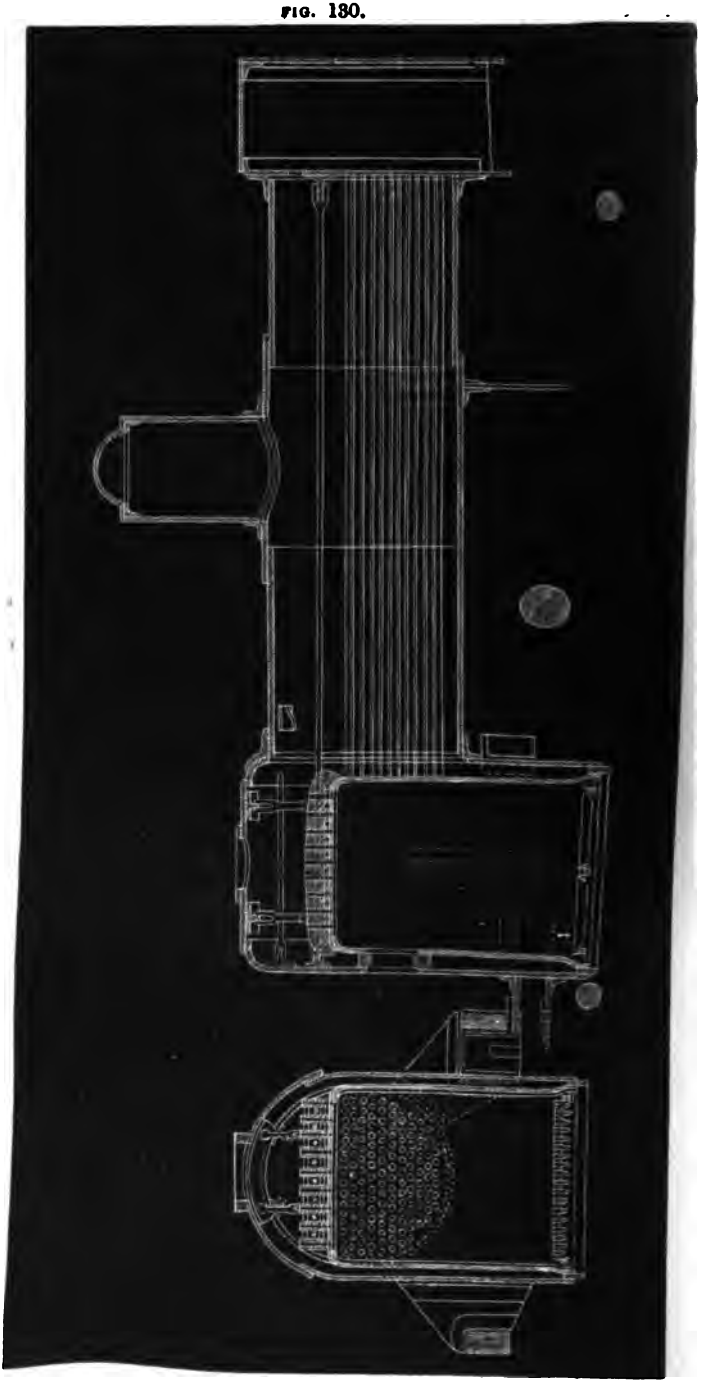


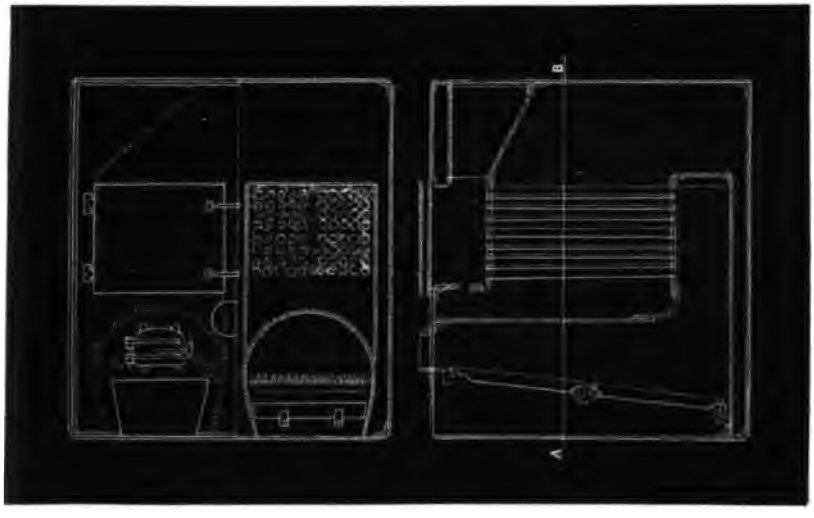
FIG. 130.



before escaping to the chimney. These boilers are often worked at a pressure of 75 lbs. to the inch. The grate is large in proportion to the consumption of fuel, as well as the heating surface, so that the gases escape to the chimney at a temperature only just sufficient to maintain a draught.

In marine engines and locomotives, where space must be economised and high chimneys cannot be employed, while a very great consumption of fuel is necessary to raise the requisite amount of steam and create the draught, a totally different construction of furnace is required. Figs. 130 and 131 show the construction

FIG. 131.



of the furnace and boilers of the locomotives manufactured at the works of Messrs. Stephenson, at Newcastle, the general principle of which consists in burning the fuel in front and below the great body of the boiler, in a space surrounded on all sides except the front by a thin stratum of water, enclosed between strong wrought-iron plates, and which forms a portion of the boiler; the heated gases from the fuel, before escaping to the short chimney, are obliged to pass through a numerous series of metal tubes surrounded by the water of the boiler, by which contrivance the heating surface is enormously increased.

Messrs. Ebelmen and Sauvages undertook a series of experiments, the object of which was the analyses of the gases issuing

from the furnace of the locomotive engine. The results obtained from a considerable number of analyses, prove the possibility of establishing a definite theory of this important class of furnaces, which have been hitherto constructed upon notions often contradictory. They have clearly proved that these furnaces are much more perfect than they are generally believed to be, and that the combustion is more complete in the furnaces of a locomotive than in that of any fixed engine.

The experiments were made on each of the three types of engines used on the Lyons Railway, viz.

Passenger engines	not coupled.
Mixed traffic engines	4-wheel coupled.
Goods' engine	6-wheel coupled.

The composition and nature of the gases varies necessarily with the quantity of air which passes through the fire, and this quantity depends on the tension of the steam at the escape or blast pipe.

The proportion of carbonic acid contained in the gases of the locomotive is greater than is contained in the gases from ordinary fixed engine furnaces, while the proportion of free oxygen corresponding to the excess of air in the draught is less in the locomotive furnace, a result clearly proving that there is a greater useful effect obtained from the fuel.

In the experiments on the passenger engines, and on the mixed traffic engines, the proportion of carbonic acid rose from 12.42 to 18.49 per cent of the volume of gas, without there being any production of carbonic oxide. The higher percentage represents a result approximating very remarkably to the number 20.80, which represents the proportion of carbonic acid in the case of combustion *theoretically perfect*, or in which all the oxygen would be converted into carbonic acid.

The combustion in passenger engines is almost perfect, and in the mixed engine, provided the fire is attended to by an experienced stoker, it is nearly as good.

These furnaces produce little or no carbonic oxide. The proportion of the gas rarely exceeds 2 per cent.

The goods engines, the grates of which are often charged with a great depth of coke, produce a greater amount of carbonic oxide; the quantity rose as high as 7.58 when the fire was 40 inches deep.

The composition of the gas varied according to the range of

tube from which it was collected. It would certainly be possible to adopt arrangements which would permit of this carbonic oxide being usefully burnt, and thus improve the beneficial effect of the fuel in these engines.

During the stoppages of locomotives, or after the closing of the regulator, the gases contain a still larger proportion of carbonic oxide. It often reaches 12 per cent of the volume.

These results are quite in accordance with practical experience in reference to the consumption of fuel in different engines. They indicate a limit of the depth of fire which it is not prudent to exceed, and also what amount of economy can be effected by the intelligent employment of expansion and variable blast pipe, according to the depth of the fuel in the fire.

Consumption of Smoke.—The prevention or consumption of smoke from boiler fires, has lately attracted great attention in this country. A public meeting was held by circular in 1842, in Leeds, where numerous patentees and others attended; a committee of the House of Commons has collected evidence with the view to legislation, while the Health of Towns Commissioners have drawn increased attention to the whole subject, by an attempt to estimate the many damages the public sustain from unconsumed smoke. There have also been numerous patents secured, independent of many other plans which have been suggested, as capable of removing or modifying this evil.

Smoke being the result either of a deficient supply of air or of an excessive supply at too low a temperature, it is extremely difficult, in consequence of the nature of the fuel ordinarily employed in this country, to suggest a plan which shall be applicable at once to the volatile portion of the coal and the coke which remains on the grate. There are also several descriptions of furnace—for example, glass-furnaces—in which it is almost hopeless to expect that smoke can be entirely prevented.

Smoke is produced in greatest quantity on the addition of fresh fuel to the red-hot coke on the grate, and is due to the process of dry distillation, which immediately takes place, evolving a large portion of gaseous matter from the coal, which there is either not sufficient air fully to consume, or the flame of which is cooled so much by contact with cold surfaces or cold air, as to cause a deposition of solid carbon. The prevention of smoke does not, however, necessarily involve perfect combustion of the fuel; as, if smoke be prevented by greatly limiting the supply of cold air,

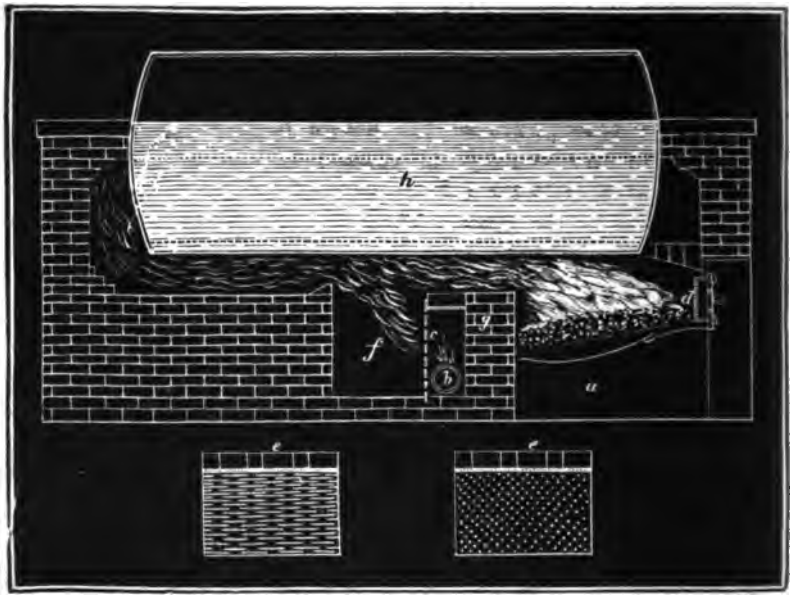
which may sometimes be done, a large portion of the active power of the coal may ascend the chimney in the form of invisible carbonic oxide, which, from deficiency of oxygen, has escaped conversion into carbonic acid. The analyses of the gases escaping by the chimney will, however, prove whether this be the case or not. On the addition of fresh fuel, an additional supply of hot air is required to consume the volatile products which immediately escape from it, and it is this necessary irregularity, or intermittent nature of the supply, which is so difficult practically to regulate.

Wood and turf may be burnt in a manner so as to reverse the ordinary position of the flame, as is the case with the fires in potters' kilns; which arrangement greatly tends to prevent smoke.

A bridge in front of the flame is sometimes employed with indifferent success for the same purpose.

Watt first suggested the idea of introducing a current of cold or hot air into the flame to prevent smoke, and a plan for carrying out this idea was patented by Robertson. The idea has since been practically applied in a great variety of ways; the air has been conducted in flues by the side or under the fire, or in the chimney, to the back of the grate, and there allowed to come in contact with

FIG. 132.

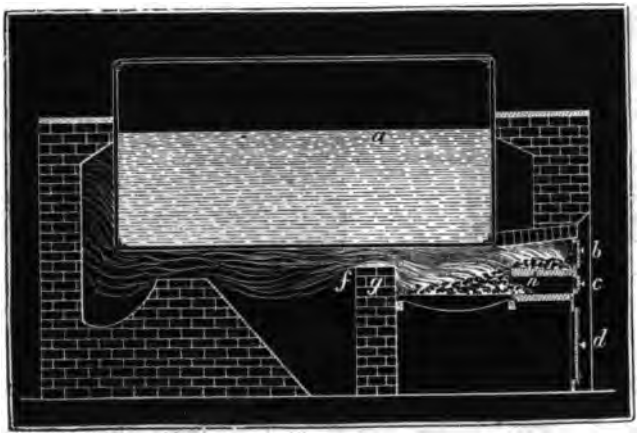


the flame. The following two plans are illustrations of this principle.

Mr. Williams' patent consists essentially in admitting a current of air behind, or through the fire-bridge, in several small jets or streams, so as readily to mix with the mass of heated hydrocarburets in their escape from the fuel on the grate bars. Fig. 132 shows the manner in which this plan is adapted to a boiler-fire, *h* represents the boiler; *d* the fire-door lined with fire-clay; *a* the ash-pit, whence the coke on the fire-grate obtains its supply of air; *g* the fire-bridge, behind which is an iron box *e* pierced with a number of small holes, through which the air streams from a tube *b* communicating with the outside. The space *f* is intended to act as a diffusion chamber for the more perfect mixture of the air and gases.

Messrs. Howard and Co. have adopted the plan indicated in Fig. 133, which represents a front view of the boiler and fire

FIG. 133.



arrangements, where *a* is the boiler, *b* the feeding door, *c* door for removing the scars, &c., *d* the ash-pit door, through which the admission of air is regulated by slides, *e* another door for the regulated admission of air to the posterior part *f* of the fire-bridge *g*. The coking plate *h* must be built of fire-brick or stone. The coal is first coked on the above plate, and then pushed over on to the grate bars, where there always exists a bright surface of burning coke.

The gases generated in coking a fresh portion of coal pass over

this heated surface before they come in contact with a fresh supply of warm air at *f*, and thus an almost perfect combustion of smoke is the result.

The saving in fuel produced by these plans varies from ¼ to ½ of the whole, and is therefore well worthy the attention of manufacturers. A very beneficial result would follow the previous coking of the coal on a broad plate made of stone in front of the fire, and the admission of a fresh supply of air at the back of the fire-bridge.

Double fires were also invented by Watt, in one of which coke was burned, while the flame of the other, consuming coal, passed over it, or the two were alternately charged with coal, and by means of dampers the flame from the last charge carried over that which had become converted into coke.

The same idea has been carried into practice with some old boilers at the St. Rollox Chemical Works, Glasgow, and found

FIG. 134.

FIG. 135

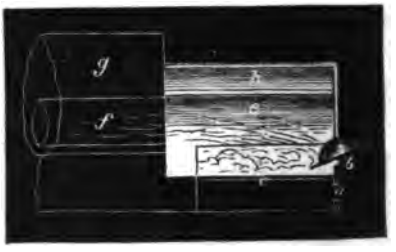
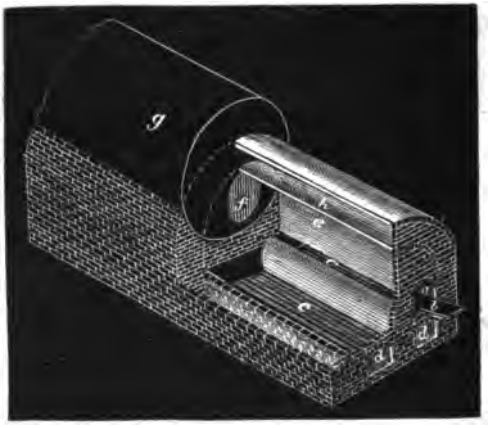


FIG. 136.



to succeed admirably, as far as the prevention of smoke is concerned; but whether the removal of the furnace to so great a distance from the boiler, and away from the action of the radiant heat, may not involve a loss of heating power, has not, as far as we can learn at present, been accurately tested. Fig. 134 shows a front elevation of the double furnace, Fig. 135 a longitudinal section through one of the fires, and Fig. 136 an isometrical projection of the boiler and furnace. The boiler is tubular, and was originally furnished with the ordinary central furnace in the interior. The furnace is now built 6 feet from the front of the boiler *g*, a double arch enclosing an air-chamber *h* being thrown across just above the cylindrical space *f*, which is converted into a flue. Below this arch two furnace-grates are constructed, separated from each other by a low fire-brick wall, but both in direct communication with the flue *f*; *d d* are the openings to the ash-pits. There are no doors either to the furnaces or ash-pits, but a slanting plate of iron *b* is placed across the furnace-mouth in such a manner that a current of air passes below it and impinges on the fuel, while slack or small coal is heaped upon it so as to fill up the furnace-mouth almost entirely, leaving a very narrow space above it for the entrance of air. The furnaces are charged alternately, so that when the stoker thrusts the slack from the plate into the one grate, the gas generated is brought into contact with the hot gases from the red-hot coke on the other, which must contain a sufficient quantity of uncombined oxygen fully to consume the hydrocarbons. The products from the combustion of the fuel are thus wholly consumed before coming into contact with the comparatively cold surface of the boiler, and no smoke or soot can be deposited, none having been produced. The double arch is of great service in retaining the heat of the furnace; but it appears to us that it would be a more advantageous arrangement if the boiler were placed immediately upon the bridge of the lower arch, and the hot gases were made to return through the central flue to the front, and again by side flues to the back of the boiler, and thence to the chimney; the radiant heat then communicated to the arch would very considerably increase the temperature of the return flues. A similar mode of setting, as applied to a waggon-shaped boiler, is shown in Figs. 137, 138, and 139, Fig. 137 being a front elevation, Fig. 138 a vertical cross section, and Fig. 139 a longitudinal section on the crooked line *a b*, Fig. 138. An arch is thrown over the furnaces to some distance beyond the back of the grates, and forms, with the

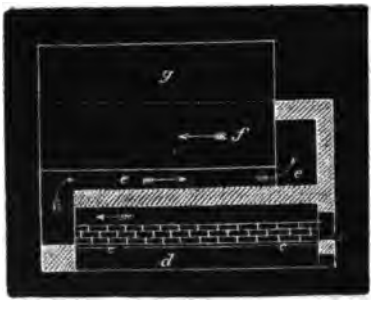
bottom of the boiler, the first flue through which the heated gases pass from the back to the front of the boiler, to return

FIG. 137.

FIG. 138.

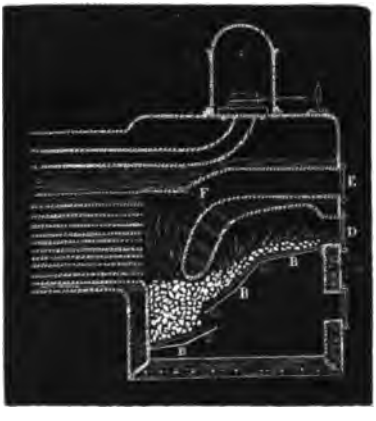
again to the back through the side flues *f f*, and thence to the chimney; by this arrangement, a very large heating surface is exposed to the action of the flame and gas, although by the intervention of the arch the combustion may be rendered perfect before the gases come into contact with the boiler, and no smoke can be formed.

FIG. 139.



Chanter, by inclining the grates so as to allow the coal when converted into coke to fall from the upper to the lower, has succeeded in consuming the smoke entirely in locomotive and other fires. Fig. 140 shows the arrangement applied to a locomotive. *A* is the fire-space; *B B B*, three grates placed at different inclinations; *C* part of the boiler, extending into the centre of the fire; *E*, a door for the introduction of coke through the channel *F*. When ⅞ths of coal and ⅛th of coke were consumed on these grates, no smoke was produced.

FIG. 140.



The cause of smoke in fires being principally due to the mode of feeding the fire with fuel, it was supposed that by affording a regular supply at short intervals, it might be entirely obviated.

Bruton constructed an apparatus in connection with a steam boiler which allowed a certain amount of fuel to be discharged at intervals of half a minute from a hopper on to the grate, and succeeded in almost entirely consuming the smoke of the boiler-fires; the grate in this arrangement was circular, and gently rotated by machinery.

Collier produced a similar result with a stationary grate by crushing the coal as it descended from the hopper and propelling it by a kind of fan into the red-hot fireplace, while an oscillating motion was communicated by machinery to the bars of the grate, to free them from ashes and clinkers.

Both the foregoing arrangements were found far too complicated to be generally adopted, but the following, applied by M. Payen, at Grenelle, is much simpler, and has worked for years without smoke and with great economy of fuel.

FIG. 141.

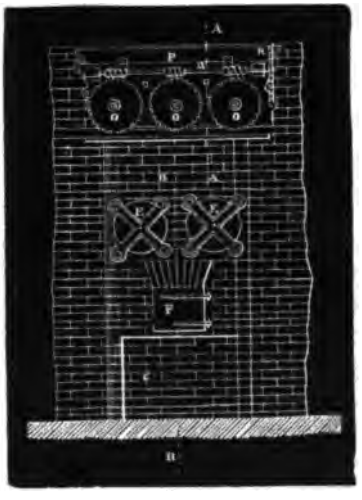


FIG. 142.

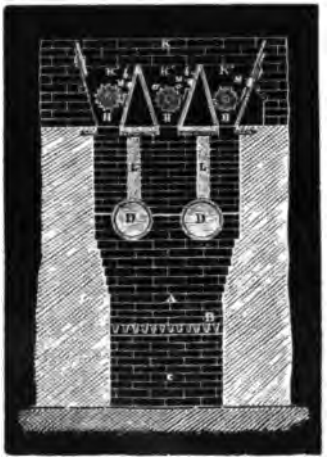
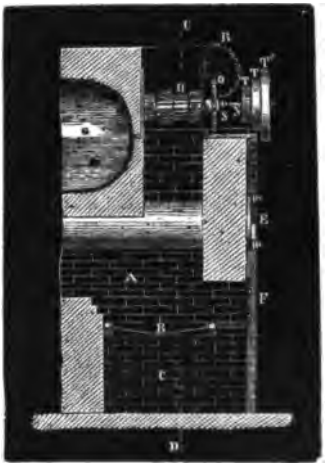


Fig. 141 is an elevation of the furnace and fuel-distributor; Fig. 142, a vertical section on the line *C D;* Fig. 143, a vertical section on the line *A B*. *A*, fireplace; *B*, fixed grate; *C*, ash-pit; *D D*, boilers; *F*, fire-door; *G*, boiler; *H H*, quadrangular axes supporting four cylinders, with alternate teeth or

FIG. 143.



grooves; *K*, hopper, separated into three compartments, *K' K' K'*, into which the broken coal is thrown; *M M M*, slides for regulating the admission of fuel to the grate; *O O*, toothed wheels attached to the grooved cylinders *H H*, and moved by the endless screw *P*, attached to the shaft *Q*; *R*, toothed wheel, set in motion by the endless screw *S*, attached to the shaft *N*, and transmitting motion to the shaft *Q* and the grooved cylinders *H H*.

Two contrivances enable the supply of fuel to be varied in this apparatus, the one consisting in the alteration of the size of the apertures by changing the position of the slides *M M M*, and the other in the three drums *T T T*, of different diameters, which when adjusted, communicate different velocities to the grooved cylinders *H H*.

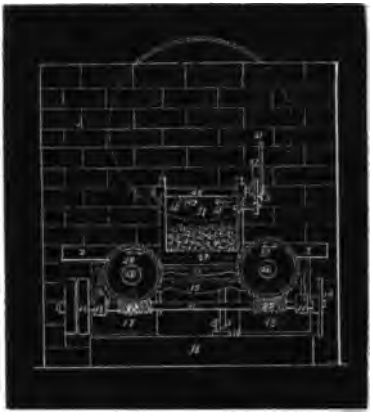
These cylinders revolve about 45 times per minute, and discharge about 33 lbs. of coal per hour into the grate. The machine is estimated at 6-horse power, and is therefore worked with about 5½ lbs. of coal per horse power per hour.

The most perfect consumption of smoke is effected in the travelling grates, which were first invented, and in their most perfect form by Mr. J. G. Bodmer. Economy of fuel and the consumption of smoke are the great advantages of these grates. Although the expensive nature of the original invention has hitherto precluded them being generally used, several modifications upon the same principle have been successfully introduced by Jukes and Haseldine, both of whose grates are employed at Price's Patent Candle Company's Works at Vauxhall, and found to consume inferior coal without smoke with considerable advantage to the company.

The annexed drawings show the application of Bodmer's screw-grate to a common cylindrical boiler, set in brick-work. The man-hole, safety valve, &c., are omitted, as these may be made in the ordinary manner.

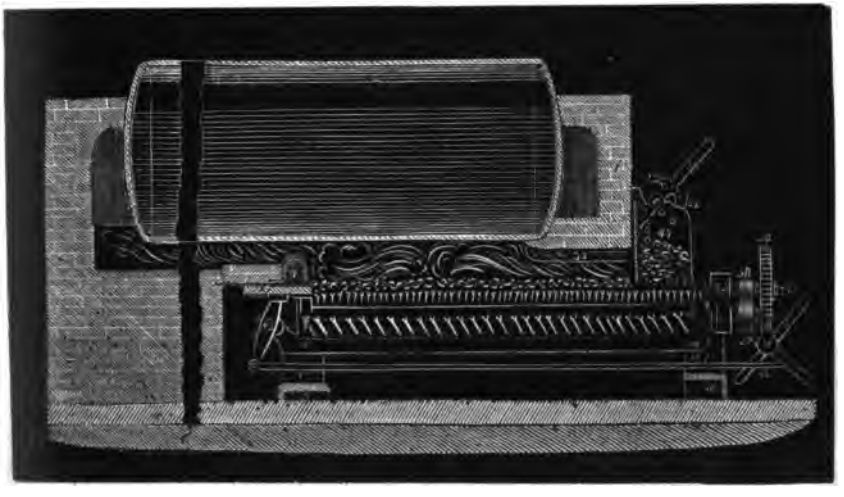
Fig. 144 is a front view of the brick-work and grate. Fig. 145, a longitudinal section. Fig. 146, transverse section; and Fig. 147,

FIG. 144.



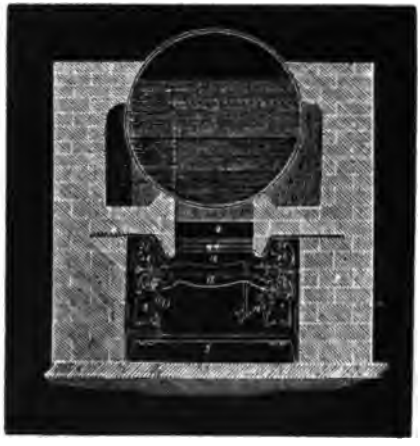
a horizontal section above the grate-bars. 1, is the brick-work; 2 and 3, cast-iron plates, which rest upon the brick-work 1, and support that portion of the brick-work above, which constitutes the hearth and the bottom part of the flues, and which is best seen in Fig. 146. The bridge 4 (see Fig. 145) is here made of wrought-iron plates, and so constructed as to be kept cool by a stream of water from above, in the usual

FIG. 145.



manner, and to be easily removed when burnt. The brick-work behind the bridge is hollowed out and arched over as usual, (see Fig. 147.) The bottom plate 5, is fixed to a stone, or to the flag of the floor, and supports the standards or frames 6 and 7, to which the screw-bearings 8 and 9 are cast, and to which the great rails 10 and 11 are fixed, which support the grate-bars 12. The return rails 13 and 14, upon which the grate-bars return, and which are marked 15, are fixed to the same standards as the rails above. The grate-rails 10 and 11 are cast in the shape of an an-

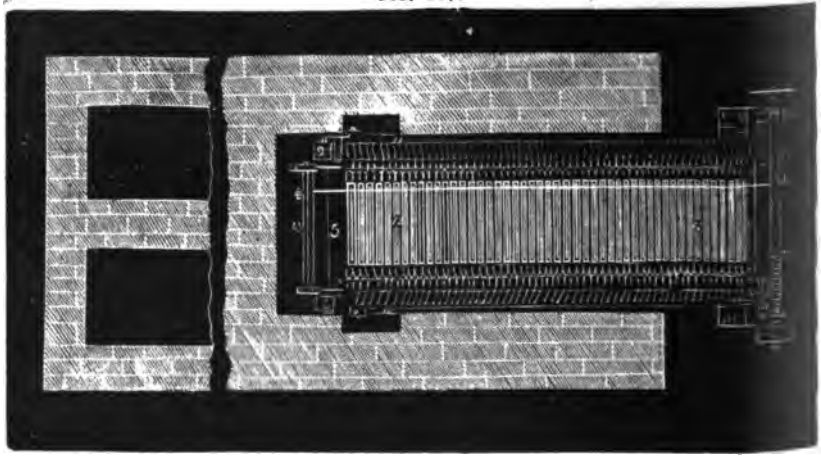
FIG. 146.



gular plate, and strengthened by brackets, for the purpose of making them strong enough to support the grate-bars and the coal. The bottom plate 16, in front, is similar to that already described; but the standards 17 and 18 are so arranged as to carry the bearings 19 and 20, in which the worm-shaft 21 revolves; and instead of having the screw-bearings 22 and 23 cast to it, they are fixed by bolts, so that they can be easily removed. The gate-screw 25 has a left-handed thread, and the gate-screw 24 a right-handed thread, and they are so constructed as to keep the grate-bars close together until they arrive at *a* (see Fig. 145), then the space between them begins to increase, so that at *b* they assume their full distance, which is the same until they arrive at *c*, when they begin quickly to approach again, so that at the bridge they are only about one-third of their former space apart.

The screws are cut in such a manner, as not only to keep the grate-bars at those described distances, but also to give them an

FIG. 147.



increasing rocking motion, which begins at *d*, increases as far as *e*, remains the same as far as *f*, and dies away into a regular screw-thread towards the end of the screw. It is clearly shown in Fig. 147 that the rocking motion of the bars is accomplished by what is vulgarly called a drunken screw-thread, and that the grate-bars are kept close together in that part of the grate in which the hopper is placed, merely by having the screws cut to a proportionately finer pitch; and this is simply for the purpose of preventing the fine coals from dropping through the grate-bars.

Suppose the coal to be put into the hopper, as shown in Fig. 145, and the grate-screws, between which the grate-bars are placed separately, to be put in motion by a strap working on a pulley 26, which is fixed on the worm-shaft 21. The right-handed worm 27 (see Fig. 144) gears into the worm-wheel 28, fixed upon the left-handed screw 25; and the left-handed worm 29 gears into the worm-wheel 30, fixed to the end of the right-handed screw 24. It is thus evident, that when the worm-shaft causes the worm-wheels 28 and 30 to move in the direction of the arrows, (see Fig. 144), the grate-bars will advance, and carry as much coal into the furnace as will be admitted by the position of the slide-door 31. As the coals will be ignited by degrees as they make their appearance under the brick-arch 32, it is evident that the gas must generate slowly and gradually, and pass in a regular and uninterrupted stream over the ignited surface of the whole grate.

It is evident that, as the gases are generated near the hopper, they will have to pass over the whole surface of the ignited fuel, and thus become heated for ignition, and consequently consumed before they arrive at the bridge. Sufficient air can also be admitted, either on both ends of the grate-bars, or by a few tubes through the brick-work; and thus not only is the smoke consumed, but the heating power of the coal increased to a very great extent.

The rocking of the bars is made to begin at a place marked *d*, where the coals are already beginning to coke, and the danger of working the small coals through the grate-bars removed; the grate-bars are made to perform an equal and strong rocking motion from that part of the grate marked *e*, to that part of the grate marked *f*, by means of which the coals are kept in constant motion, the ashes removed from them, the contact of the coals changed, the grate-bars prevented from clinking, and a clear and brisk fire kept up without that extraordinary draught which is required in other grates.

To prevent the heat becoming too great at the bridge, the spaces between the grate-bars, from *f* to the bridge, are gradually diminished, thus reducing the admission of air; and the rocking is made to cease in that part of the screw in which the hindmost grate-bar is caused to drop, by means of the tappets 33 and 34, into the return screws 35 and 36, which are placed directly under the grate-screws. The return-screws are caused to revolve by means of the pinions 37 and 38, placed behind the worm-wheels 28 and 30, and the pinions 39 and 40, fixed to the ends of the return-screws; and as the screws thus revolve in opposite directions and exactly at the same speed, it is evident that the thread of the return-screws will receive the grate-bar (which is forced down by the tappets) in its thread, and carry it again to the other end of the screw; where it is lifted up by the tappets 41 and 42 of exactly the same construction as the tappets 33 and 34, is placed into the thread of the top screw, and forms again a portion of the grate. The thread of the return-screw is of double the pitch of the grate-screw, for the purpose of allowing the ashes to descend and the air to ascend. It is quite clear, that by this arrangement any defective grate-bar can be taken out, and a new one put in its place; and that in fact the whole set of grate-bars can be exchanged without the slightest interruption of the combustion. The grate-bars which form the grate are supported by the rails 10 and 11, as already explained, and return upon the rails 13 and 14. To the ends of the rails 13 and 14 a fork is cast, by which the scraper-shaft 43 is supported, the arms of which take into an iron slide 44, to which the wrought-iron scraper-plate 45 is fixed. It is under this plate where the grate-bars descend; and for the purpose of getting rid of the clinkers, &c., which of course are all carried to the bridge, the plate or slide 44 is drawn back by means of the bar 46, and thus the clinkers are allowed to drop. The hopper 47 consists of cast or wrought-iron plates, and may either be left open at the back, or closed by a sheet-iron plate, which can easily be removed for the purpose of having access to the grate; and the slide-door 31, which regulates the depth of the coal, is worked by means of the shaft 48, the arms 49 of which take into the snugs 50 and the lever 51; and the slide-door is held in its place by the toothed segment 52, and click 53.

The cross 54 on the worm-shaft 21 is simply for the purpose of moving the grate by hand, which in most cases is required when a fresh fire is put in; this is done in the usual manner, except

that the coals towards the bridge are laid considerably thinner than nearest the hopper.

As very little power is required to work this grate, a small working cylinder of a few inches only in diameter, according to the pressure of the steam, can be placed upon the top of the boiler to work the grate and the feed-pump, which will be convenient in such places where boilers are used for other purposes than steam engines. By a simple arrangement and a pair of cone pullies, the heating power of the grate can be increased or diminished as the consumption of steam and the pressure may require, and the grate can be made self-acting in every respect.

Only one application of the grate is here given; but it can be applied to almost any sort of boiler: namely, to boilers with a series of tubes, without any brick-work; to boilers with heaters set in brick-work; or it may be applied to boilers with large flues, in a similar manner to ordinary grates, as well as to marine boilers of various construction, by slight alterations of the frames, without deviating in the slightest degree from the principle. The grates may also be applied to puddling, air, and steel furnaces, and many other purposes where economy of fuel and entire combustion of smoke are desirable.

This grate is superior to Mr. Bodmer's drum-grate and chain-grate; the latter of which has been brought into public notice by Mr. Jucks, and which appears to give great satisfaction with respect to economy and regularity in the combustion of the gases; but the screw-grate is preferable, on account of its simplicity, the facility of repairs, change of grate-bars, and more perfect and economical combustion.

Mr. Prideaux, conceiving that expensive and complicated arrangements like the grate just described will never force themselves into general use, has endeavoured to adjust the supply of air to boiler-fires in a manner to meet the fluctuating demands of the fuel by a self-acting valve applied to the fire-doors of the furnace. This invention is extremely simple in principle, and has been most favourably reported on by naval officers who have witnessed its effects upon marine boilers, where it not only most completely prevents smoke and consequently increases the effective value of the fuel, but likewise diminishes the excessive and highly injurious temperature of the furnace-room or stoke-hole. No change is required in the construction of the grate, and the existing arrangements for coaling remain untouched; but a hollow or double

fire-door is substituted for the single one generally used, the inner plate of which is pierced with numerous small holes, through which the air, warmed by contact with the hot metal, obtains access to the furnace and is subdivided into minute jets which, coming into contact with the products of combustion, completely consume them. The supply of air is regulated by a sliding valve in the face of the outer door, attached to a lever, which is raised as soon as fresh fuel is thrown upon the fire, and falls gradually by its own weight, closing slowly the valve, and thus diminishing the supply of air with the diminishing requirements of the fuel. The area of the valve, and the time occupied in closing, must be regulated according to the nature of the fuel and other circumstances, which may vary in each particular case. It is the supply of hot air just at the time when it is required, and in the proper quantity, that constitutes the merit of this invention, while the double door prevents the radiation and consequent loss of heat. The adaptation of simple apparatus of this kind, in conjunction with a fire-brick arch immediately above the burning fuel to prevent the sudden cooling of the unconsumed products of combustion, will doubtless prove a great source of economy in boiler-fires.

Anthracite is much more difficult to burn under boilers; a much thicker stratum must be kept at a red heat, or the fire is liable to be extinguished; many varieties will not bear stoking without falling to a fine powder, which then arrests the draught; others produce a great amount of clinker. Those which have but little residue and fall to pieces, like the majority of the Welsh and American anthracites, may be burnt in the manner proposed by M. Player, and shown at Fig. 147. A fixed grate, with straight fire-bars, is fed from a hopper kept constantly filled with anthracite; the fuel then forms a cone, from the end of the hopper to the grate, and descends as it is consumed. There is no door to the grate, the entire quantity of air being supplied from below the bars: the fuel being heated as it descends the hopper, does not cool the fire, as is the case when it is

FIG. 147.

introduced cold through a fire-door, and the decrepitation, if there be any, occurs before it reaches the grate. With some varieties it would be necessary to supply some means of clearing the grate-bars of clinker. In burning fuel of this description, an accurate regulation of the draught is very necessary, so as to allow no carbonic oxide and as little uncombined oxygen to escape by the chimney as possible.

Boutigny proposes the following novel arrangement for raising steam.

Noticing that all bodies, solid or liquid, only evaporate by means of their surfaces, and taking advantage of this fact, he proposes to employ a cylinder, the bottom of which is semi-spherical, and the top tightly screwed down, to which the usual accompaniments of a steam-boiler are attached—viz.: steam- and feed-pipes, man-hole, safety-valves, steam-gauges, &c.

The cylinder contains 5 to 7 tin-plate diaphragms with the edges turned up; they are alternately convex and concave, pierced with small holes from below upwards.

The water, before arriving at the bottom of the cylinder, where it assumes the spheroidal form, has passed over a great surface, falling as a fine rain from one shelf to another, collecting in the one towards the centre, and in the next towards the rim.

The arrangement for collecting the steam between the two last shelves, tends to maintain the whole interior at the same temperature, and to produce steam of any degree of tension.

The cylinder is heated alone for a few minutes, after which a small quantity of water is admitted, and in twenty or twenty-five minutes more, the apparatus is ready for work.

The following are the details of an experiment with this boiler:

Duration of the experiment	9 hours.
Weight of coal burnt	182 lbs. (81 kilogr.)
Weight of water evaporated	790 lbs. (350 kilogr.)
Temperature of the water used	39° C.
Pressure	10 atmospheres.

The coal was not of good quality, and was rarely equal to 6,000 heat-degrees per kilogramme, and assuming with Morier that 50 per cent is the maximum available effect, we have:

$$81 \text{ kil.} \times 6{,}000 \times 0.50 = 243{,}000 \text{ degrees.}$$

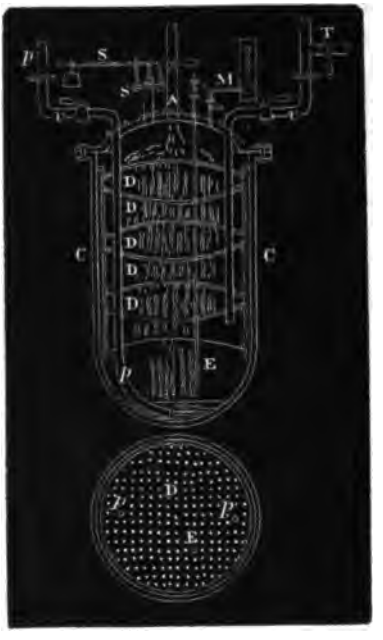
Now, 351 kilogr. water, under the above conditions, contain 351 kilogr. $(550+t-t')=242892$ degrees;

and in this formula $t = +181°$ C.
$t' = +\ 39°$ C.

hence the loss is only 108 degrees.

Fig. 148 represents a perpendicular section of the entire boiler, with a horizontal section through *C C*; *A* feed-pipe; *D D D* seven metal shelves, four of which are convex and three concave; *E* water-gauge; *M* steam-gauge; *P* pipe for cleaning the boiler; *S* safety-valve; *V* steam-pipe.

FIG. 148.



Evaporation.—The object of evaporation is to remove one or more volatile ingredients from a mixture in order to obtain the less volatile or fixed. The operation may be carried on either with or without the aid of artificial heat, in open or close vessels; and in the latter case it is more properly called distillation.

The air seldom contains the maximum amount of moisture which it is capable of retaining in the state of vapour, and liquids

exposed to it evaporate more or less quickly, according to the extent of surface exposed. In describing the methods for obtaining salt from the water of brine springs, in our second volume, an account is given of the system adopted for spontaneously evaporating the weak liquors, which consists in exposing the liquid in very shallow ponds to the air and sun, or by causing it to flow over a very extensive surface of twigs in the graduation-houses. No fuel is employed in this process of evaporation. An artificial current of air at the ordinary temperature produced by mechanical agency, has also been employed to produce evaporation where a high temperature would prove injurious to the product.

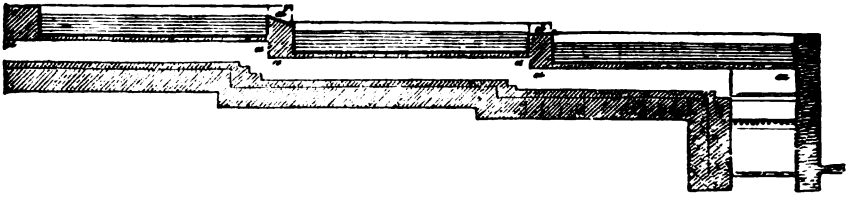
Evaporation in open pans. — The most simple method of evaporation by the agency of fuel, is to place the liquid in a pan or vessel immediately over a fire, or exposed to the flues through which the smoke and hot gases from the fire are passing to the chimney. Although evaporation takes place at all temperatures, it proceeds much more rapidly as the heat increases, and it has been proved both by calculation and experiment that less fuel is required to evaporate a given weight of liquid at the boiling point than to evaporate the same weight at any lower temperature. The general practice, however, is to employ a much larger heating-surface in evaporating vessels than is usual in steam boilers, and the smoke and hot gases are cooled down as much as is compatible with a good draught before escaping to the chimney. There is no economy of fuel in using very deep evaporating vessels, as the quantity of liquid evaporated, for the same amount of fuel consumed, depends solely upon the extent of surface exposed to the fire or source of heat.

When evaporation takes place at the boiling temperature, the vessel may be closed, with the exception of a sufficient aperture for the escape of the vapour, without materially affecting the rate of evaporation; but there is always a loss of heat if the exposed surface of the cover is not itself covered with some non-conducting substance.

The open pans employed in concentrating oil of vitriol are shown in Fig. 149. They are constructed of lead, and arranged at gradually increasing levels over a single flue, passing from the fire in such a manner that the weak acid is exposed in the pan at the highest level to the least heated part of the flue, and can be let off into the others, which are more strongly heated, as it becomes concentrated and requires a higher temperature for

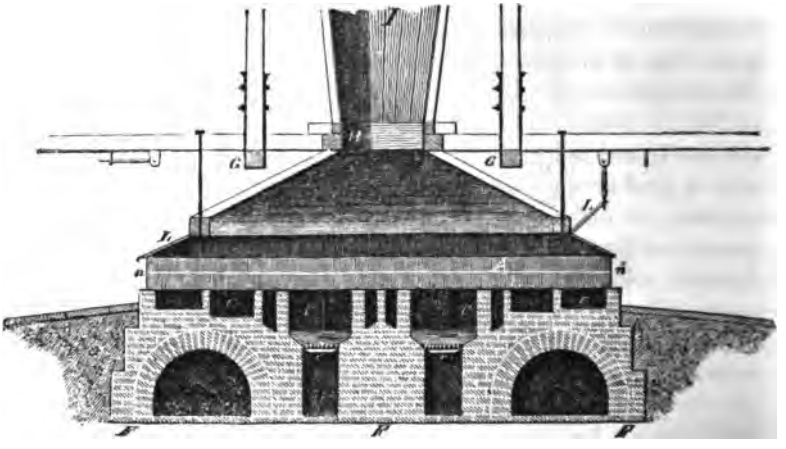
evaporation. Surface evaporation in close furnaces, as described below, is the plan adopted in large vitriol works in this country.

FIG. 149.



The large shallow pans employed in evaporating the brine for the production of salt are shown in Fig. 150, and the arrangement of the flues conveying the smoke and hot

FIG. 150.



gases in Fig. 151. These pans are flat quadrangular vessels, constructed of sheet-iron, often 60 feet long by 30 in breadth, and by the arrangement of the space below them, the flame from the two furnaces is brought into contact with the entire bottom surface of the pan. In order to increase the rapidity of the evaporation, the pan is nearly covered by a large wooden funnel, opening above into a vapour-chimney *I*; the lower part of this hood or funnel is constructed of planks, which can be turned up so as to admit the air freely to the surface of the

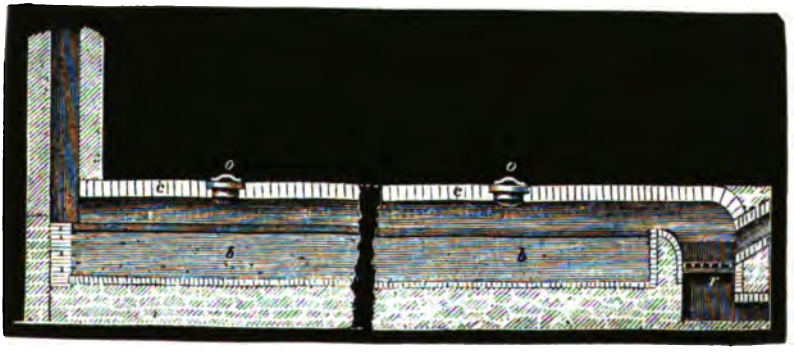
liquid from the side opposed to the wind. The vapour has sometimes been carried into the chimney instead of escaping by a separate funnel; but when it is produced in considerable

FIG. 151.

quantity, the draught is liable to derangement. This is likewise the case when the vapour is conveyed to the ash-pit. In some localities, large drying-flats for prepared chalk or whitening are connected with these salt pans, so as to employ the waste heat.

Where large quantities of weak liquors require to be concentrated, which are of such a nature as not to be injured by the products of combustion and the particles of dust and carbon

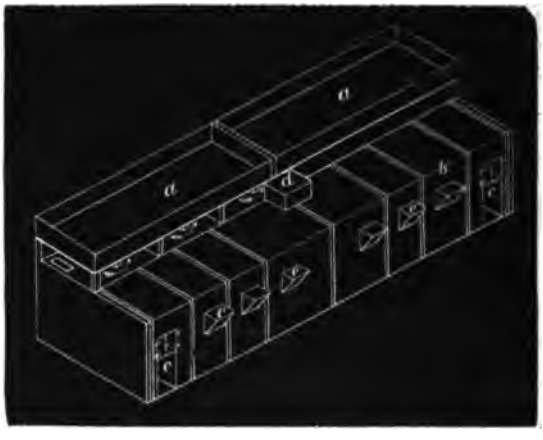
FIG. 152.



they carry with them, the flame and heated gases may be carried over the surface of the liquors. This plan of surface evaporation is practised with weak alum-liquors, as shown in Fig. 152. It was originally adopted in consequence of the sediment which is deposited during the process attaching itself to the bottom of the ordinary open pans, and causing their rapid destruction. These tanks are constructed of bricks, cemented together with a mixture of lime and lixiviated alum-shale. They are very shallow, but of great length, so as to offer an extensive surface to the current of hot air and gases. An open pan is sometimes placed above them, which serves as a feeder for the lower pan.

Fig. 153 represents a pan-furnace for boiling down liquors to dryness, where the material is not injured by an excessive temperature. The interior of the furnace is lined with sheet iron, or rather consists of a long sheet-iron pan, capable of holding 2,000 gallons of liquid. The fires *c c* are at each end, the steam and products of combustion passing off by a flue *d*. The working doors *e e e* project in front of the furnace, and facilitate the removal of the dry mass. The open pans *a a* are heated by the waste heat of the pan-furnace *b*.

FIG. 153.



Hot or cold air, driven by a fan or other machinery over the surface of a heated liquid, is a powerful evaporating agent, and its efficacy is much increased by agitating the liquid with a rouser, so as to bring as large a surface as possible into contact with the current. The plan of forcing heated air through liquids to be evaporated, which was at one time extensively practised in the sugar factories, has been entirely discarded, as not

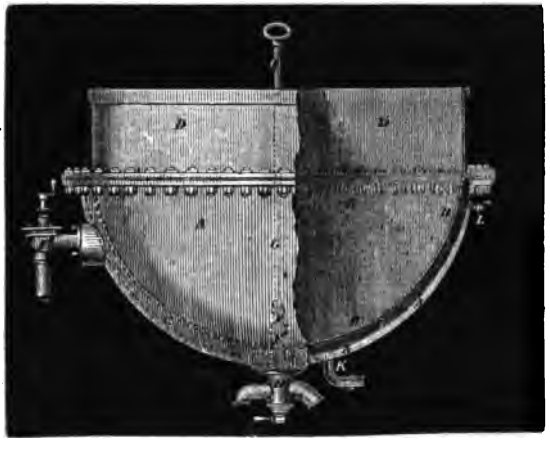
economical and frequently tending to alter the nature of the liquid.

Evaporation by Steam.—Steam is employed to evaporate liquids which contain substances liable to be altered by exposure to a higher temperature than that of boiling water or of high-pressure steam. It is applied in two ways; either to the outer surface of the pan by means of a jacket, or to the interior by means of a coil of pipes. In both cases the extent of surface must be so calculated that the same amount of vapour shall be condensed by the heating-surface as is required to be expelled from the liquid to be evaporated.

It has been calculated, that for evaporating vessels with steam jackets, every square foot of heating-surface will condense about 0.6 lbs. of vapour per hour for a difference of temperature of 1° centigrade; and a coil of pipe, not exceeding 1 to 1.3 inches in diameter, for a length of 6½ to 10 feet, will condense 1.7 lbs. of vapour per square foot per hour.

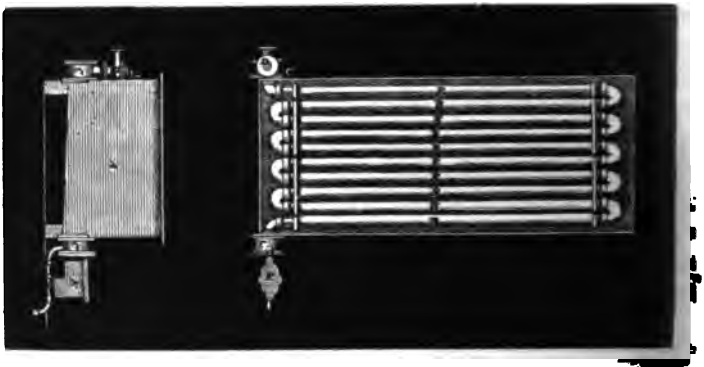
The steam evaporator, or heater, with a double bottom, as employed in the sugar factories, is shown in Fig. 154. *A* is the outside jacket, composed of cast-iron; *B* the inner copper pan; *C* the space between them, into which steam is admitted by means of the valve at *I*; *K* the pipe for carrying off the condensed water; *L* is a small cock for allowing air to escape when steam is admitted to the pan.

FIG. 154.



Open steam evaporators, heated by pipes, are shown in Figs. 155 and 156. They are large rectangular iron vessels, *A* containing a series of pipes *B B*, which work through stuffing-boxes *C*, and are connected together by gun-metal bends. The whole set of pipes can be raised at once, in order to be thoroughly

FIG. 155.



cleaned, as shown in Fig. 156. Steam is supplied to the pipes by the valve at *D*, and the condensed water flows off into *E*.

Another method of evaporating weak liquors is shown in Fig. 157. Here the steam from a vacuum-pan is introduced into a series of straight copper pipes, placed one above another, their ends being fixed into cast-iron boxes. The steam is admitted through the pipe *D*, and passes in the direction indicated by the arrows, escaping finally at *E*. The weak liquors to be evaporated are allowed to fall in a fine shower from a perforated trough *B* on to the heated pipes. A large surface of liquid is thus exposed simultaneously to the hot surface and to the air, and is concentrated while the steam in the interior of the pipes is condensed.

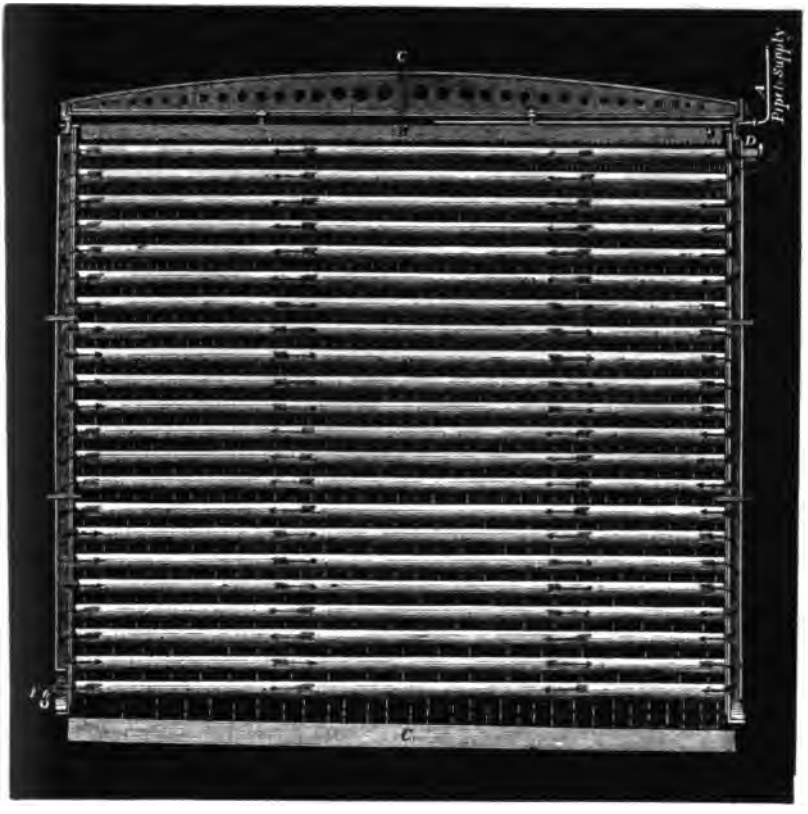
FIG. 156.

When it is desirable that the air should be totally excluded from the liquor to be evaporated, and the evaporation proceed at a temperature lower than that at which the liquid would boil when exposed to the atmospheric pressure, recourse is had to the vacuum-pan.

Fig. 158 represents the apparatus employed in concentrating sugar-liquors; *L* is a vessel for regulating the supply to the

pan, while the vessel *M* is intended for collecting any portion of the liquor which may accidentally boil over; *A* is an outer cast-iron jacket, between which and the inner copper vessel *B* steam

FIG. 157.



is admitted; *D* is the copper worm, also supplied with steam from the valve *F*. The vapour is pumped off by an air-pump through *E*, which is assisted by the condenser shown in Fig. 157, or by some arrangement similar in principle. *I* is a thermometer for indicating the temperature of evaporation; *K* a barometer or vacuum-gauge, for ascertaining the pressure in the pan. The temperature at which the liquor would boil, under atmospheric pressure, is about 250° F., and it is reduced by the vacuum to 150° F.

FIG. 158.

We are indebted to the firm of Messrs. E. and W. Pontifex and J. Wood for these beautiful illustrations connected with the production of sugar.

Distillation.—The separation and collection of a more volatile ingredient of a mixture from others which are less volatile or fixed, is called *distillation.* The operation may simply consist in raising the temperature of a mixture sufficiently to evaporate the volatile ingredient, and in condensing the volatile product, either to the liquid or solid condition; or it may involve the decomposition of the substance heated, and the condensation of the products of decomposition, when it is termed *destructive distillation.* This latter process is sometimes carried on for the sake of the volatile products, as in the manufacture of gas and gaseous combustibles. Where a solid body is operated upon, and the products are liquid or gaseous, the process is called *dry distillation,* and is generally destructive. It is called *sublimation* when the product condenses fromthe state of vapour into the solid condition, without passing through the intermediate state of liquid.

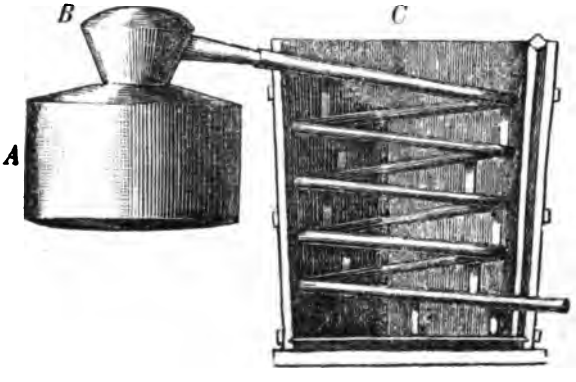
The distillatory apparatus, or still, is constructed of brick, fire-clay, iron, copper, or platinum, according to the nature of the substances to be operated upon. The escape-pipe for the vapour is generally larger than is absolutely necessary, as it is desirable the vapour should leave the still with as few obstructions as possible. Air and water are almost the only agents employed for condensation, and the condensing-pipes are generally of iron or copper, excepting in those cases where corrosive substances are condensed, such as acids, when stone-ware pipes and receivers are employed, or, in the case of vitriol, platinum and lead.

The dimensions of all the parts of the apparatus will depend upon the quantity of vapour required to be produced and condensed in a given space of time, when the specific and latent heat of the products will necessarily form an important item in the calculations.

The still is generally heated by the direct action of the fire and flues; but steam, of high or low pressure, applied either to the outer surface, or by a coil of pipe to the interior, or by both conjointly, may likewise be employed as a source of heat. Both high and low pressure, as well as heated steam, may be brought into direct contact with the substance to be distilled, where the products are of such a nature as to be easily separated from the condensed water; and lastly, the facility with which vapours rise under diminished pressure, renders the vacuum a desirable method of distillation in particular but rare cases.

The same general principles may be applied to the setting of

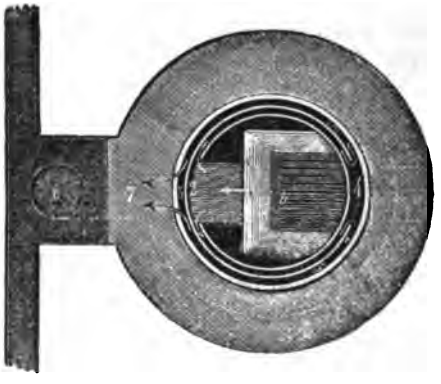
FIG. 159.



stills over the fire as were described in treating of boilers; the larger the heating surface exposed the better, provided a good draught is secured and the contents are not liable to be burned by the direct action of the fire upon the material of the still. This, however, is frequently the case, as in the preparation of spirits, where a rapid distillation is required, and rousers are frequently employed to prevent the solid contents from adhering to the bottom of the still.

Fig. 158 represents the simplest form of still, with a worm-pipe condenser. *A* is the still; *B* the head; *C* the refrigerator, kept constantly supplied with cold water, and containing the worm for the condensation of the vapour. For ordinary purposes, the diameter of the still may be 2½ times its height, and the neck about ⅓ of the diameter. It may be set in the manner shown in Fig. 159, when the flame, after leaving the bottom of the still, separates at 2 into two flues, which enclose it on either side and meet again at 4, where they again branch into two upper flues, 5 5, before entering the chimney at 7.

FIG. 159.



The simple still continues in use for many operations in manufactories, but for the production of brandy, whisky, and spirits generally, where the product requires to be redistilled before it is sent into the market, a great saving of heat, and consequently of fuel, is effected by making the wash or liquor condense a great portion of the vapour, which portion is returned again to the still, while the wash itself absorbs the latent heat. The vessel in which this is effected thus becomes a second still, or rectifier, and the product is finished in one operation.

Fig. 160 shows the apparatus invented by Dorn for this purpose. *A* is the still, heated by the direct action of the fire; *B* the head, from which a pipe *r* conveys vapour to a small refrigerator, for the purpose of testing the strength of the distil-

late; *E* is the ordinary condenser, containing worm, &c. The intermediate copper vessel answers two purposes; the upper part *c* forming a heater for the wash, while the lower compartment *D* acts as a rectifier. The heater *C*, when filled up to the

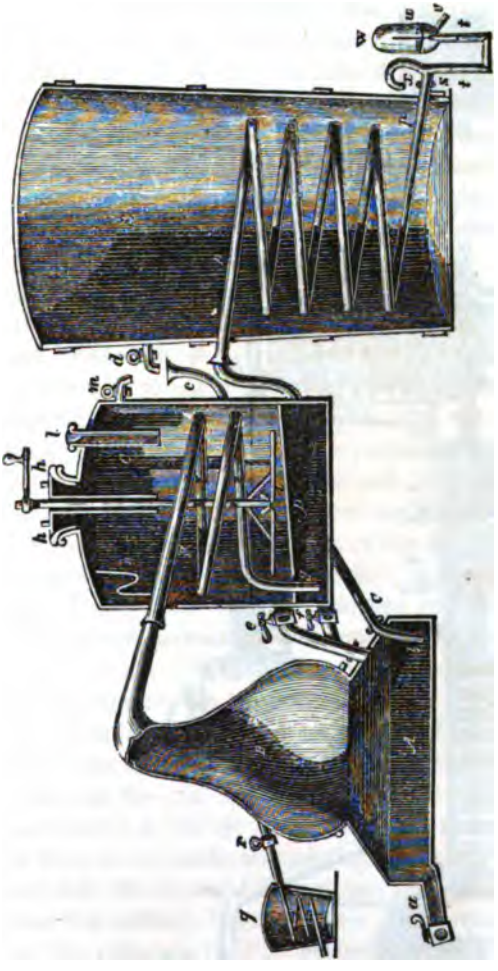
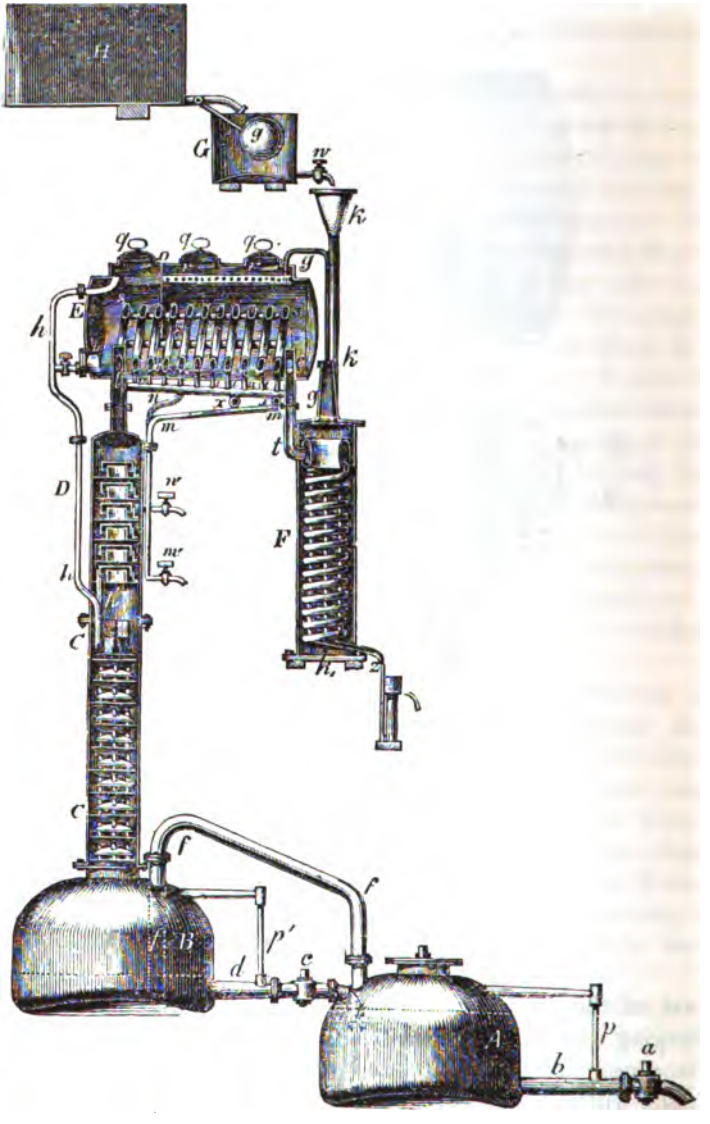


FIG. 160.

level of the cock *m*, contains the exact measure of wash for charging the still; the contents can be constantly agitated by the rouser *i*. The still and heater being both charged, the vapour will at first be completely condensed in passing through

the worm *g*, and flowing into *D*, will close the aperture of *q* with a water- or spirit-valve. When the contents of *C* become so hot that no more condensation occurs, the vapour will be forced to escape through the liquid in *D*: this becoming heated

FIG. 161.



by the constant current of vapour, will itself soon boil, and evolve vapour of greater strength than the liquid it is leaving, which is then condensed by the worm in *E*. In this manner, by one operation, spirit containing about 60 per cent. of alcohol is obtained.

An improvement upon this apparatus was made by Pistorius, who introduced a second still over the same fire. The vapours from the one still were passed directly into the wash in the other, which was thus soon brought to the boiling point, and the vapour was condensed in a rectifier similar in principle, but somewhat modified in construction, to the one just described. Alcohol of 80 or 90 per cent. was thus obtained in a single operation. Schwarz and others have improved upon the apparatus of Pistorius, but the greatest perfection in the apparatus for distillation has been reached in the arrangements of Derosne and Coffee, which are superseding all others in large distilleries. The advantages presented by these forms of apparatus consist in the more complete separation of the alcohol from the less volatile oils and water which accompany it. Derosne's apparatus, shown in Fig. 161, is extensively used in France for the preparation of brandy from wine. It consists of two stills, *A* and *B*, a distillatory column and first rectifier *C*, a heater and second rectifier *E*, a condenser *F*, a vessel *G*, which by means of the float *g* regulates the supply of wine contained in the tank *H*.

The principle of the whole method consists in bringing the wine by an uninterrupted descent into continuous contact with the vapour as it ascends. The liquid and vapour are in actual contact throughout great part of the apparatus. The fluid is thus deprived of spirit, while the strength of the spirit is increased. The wine which is ultimately distilled thus entirely replaces the water on the old system. The wine flows from *H* to *G*, in which vessel it is always retained at the same level by means of the float *g*; a small stream regulated by the cock *w* flows constantly into the funnel *k*, and enters the cooler *F* at *k'*; the portion that has already become warm by contact with the worm rises in the tube *gg* to the heater *E*, where it is discharged through a perforated gutter on to the hinder part of the coil of pipe *ss*. The wine is thus again heated, in cooling the coil through which alcohol vapour is passing and condensing, and almost acquires a boiling temperature, before escaping through the pipe *hh* to the rectifier *C*. In order that the

wine may acquire as high a temperature as possible in *E*, a diaphragm is inserted at *oo*, which separates the vessel into two compartments communicating with each other at the lowest part only, so that the wine which flows out through the pipe *k* has previously been in contact with the hottest coils of the condenser *ss*. Arrived at *C*, it falls in cascades over a series of lenticular discs of metal which retard its descent and allow time for the rectification to be effected. The residue from the rectification called vinasse, which collects almost exhausted in the still *B*, is run off into *A* through the pipe *d*, where it is boiled, and after losing the last portion of alcohol is discharged at *a*. During the distillation, *B* is filled only to $\frac{1}{4}$th of its depth, and *A* to $\frac{3}{4}$ths, which levels are indicated by the gauges *p* and *p'*. Both stills are placed over one fire, so that the effect of the steam in *B* is heightened by the direct influence of the fire.

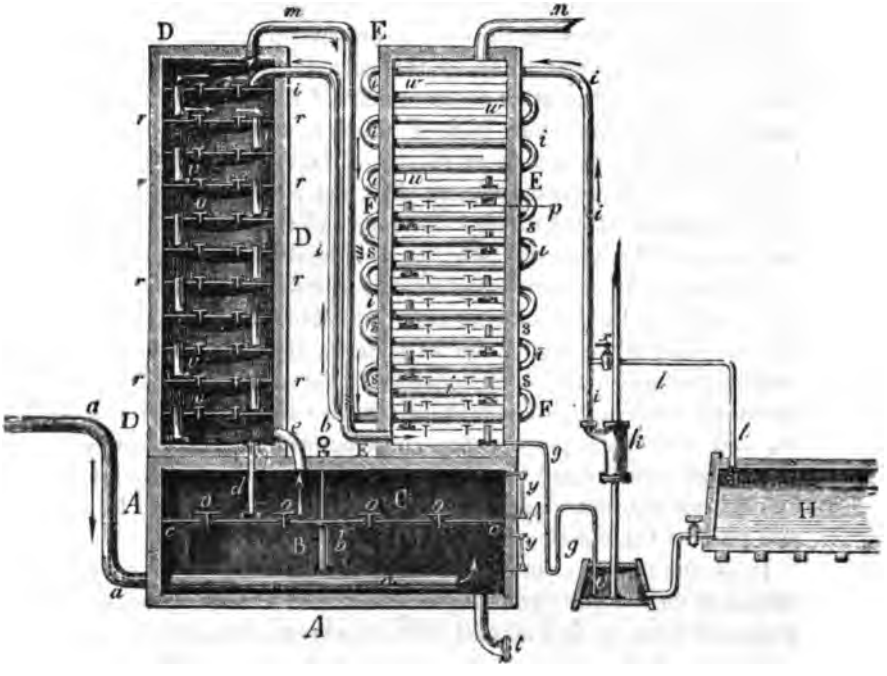
The vinasse in *A* furnishes steam for the whole process, which, with a trace of alcohol, rises in the steam-pipe *ff*, and passing through the liquid in *B*, heats it to the boiling point. The vapour rising from *B* ascends into *C*, where it meets the descending rain of heated wine, from which it extracts nearly the whole of the alcohol, and is partly rectified by contact with the outside of *C*. In *D* it meets the liquid which has been condensed by the action of the wine on the coil *ss* in the vessel *E*. This is allowed to collect on several shallow stages, and through it the vapour has to force its way under the little caps shown in the drawing, before arriving at the coil *ss*. The liquid from these stages ultimately descends into the first vessel *C*. The last rectification is effected in *ss*, and the brandy then passes off to the condenser *F*, through the worm *xx*. A quantity of more or less impure spirit collects in the lower parts of the coil *ss*, which is conducted away by the short pipes *iii* to a common pipe *vv*, whence it can be let off either into *D* to be rectified, or may be mixed with the distillate by the pipe *t*.

Coffee's still was patented in 1832, and notwithstanding its great advantages for the manufacture of raw spirits, has by no means been yet universally adopted. In principle, it is essentially the same as that of Derosne, but being intended to work mashed liquors, a separate boiler is employed to avoid the danger of burning.

Fig. 162 represents this form of apparatus. Coffee's still resembles externally a large wooden chest, being constructed of

very thick planks covered on the inside with sheet-copper. It consists of a wash collector *AAA* and two upright quadrangular columns. The one *DDD* is called the *analyser*, and is intended for rectifying the wash; the other *EEE*, the *rectifier*,

FIG. 162.



answers the purpose of a heater and dephlegmator; the lower part *FFF* acting as a rectifier for the feints, while the upper part condenses the alcoholic vapour.

The distillation is effected upon the same principle as in Derosne's apparatus, a constant current of spirituous vapour ascending in one direction being brought into intimate contact with a stream of wash descending in the other.

The wash collector *A* is separated into two compartments, *B* and *C*, by a plate of copper *cc*. The plate *cc* is perforated with holes in the form of a sieve, and is furnished with T-shaped valves *ooo*. The analyser *D* is separated by similar plates *rr* and valves into twelve chambers; and the lower part of the rectifier *FF* contains ten chambers similarly separated from each

other by the plates *sss*. The orifices in these plates permit the vapour to pass through them, but are too small for the descent of the liquid wash, which finds its way from one chamber to the other by the short pipes *d* and *v*. When the pressure of vapour is great, the valves *oo* allow it to escape.

A constant stream of wash is drawn from *G* by the pump *k* into the pipe *i*, which supplies the entire apparatus. The supply is regulated by allowing the excess drawn up by the pump to flow back into the cistern *H* by the cock *x* through the pipe *l*. The pipe *i* enters the utter compartment of *E*, where it is separated into three branches, each of which traverses by a series of bends, only one of which is shown in the drawing, the entire height of the rectifying column *EE* and *FF*, passing from the last compartment but one by the pipe *i* to the uppermost compartment of the analyser *DD*. In the analyser the wash flows from chamber to chamber, and arrives at length in *C* by the pipe *d*, whence it is let down at intervals into *B* by raising the valve *b*. This is done when the gauge at *y* shows that the chamber *c* is quite filled with liquid. It is essential that a stratum of liquid about an inch in depth should be allowed to rest on the plates *rr*, and the short pipes *v* are consequently allowed to project about that much above the level of the plate, while their lower extremities dip into shallow cups which remain filled with liquid and prevent the escape of vapour through them.

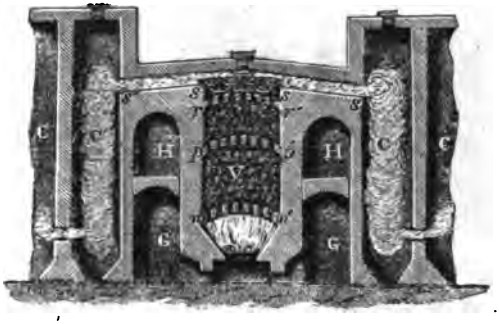
In *B* the nearly exhausted wash meets the current of vapour issuing from a boiler through *aa*, and the last trace of spirit is separated from it and carried with the vapour through the sieve apertures of the plate *cc*, passes through the entire mass of liquid in *C*, which it nearly exhausts of alcohol, and arrives through *e* in the lowest compartment of the analyser; here it ascends through the wash collected in each compartment, becoming cooler in its progress, acquiring alcohol and losing water, until it is transmitted by the pipe *mm* to the lowest chamber of the rectifier. In *F* it traverses the plates *ss* in a similar manner, passing through the feints which have collected upon them in inch-thick layers by the rectification in *E*. These feints are returned by the pipe *gg* to the cistern *G*, and pumped up again with the fresh wash. The vapour arriving in *E* by the wide aperture *u* is compelled by the plates *ww*, which are not perforated, to follow the windings of the pipe *i* in its entire length, by which means it is condensed, and the wash flowing through

the pipes heated. The condensed vapour collects on the bottom of *E*, and is conveyed by pipes at *p*, not shown in the drawing, to another condenser.

A plan similar to this has been adopted by Hill for distilling gas-water, which will be described below.

Several of the metals which are volatile at a high temperature are separated from their ores and purified by distillation. Fig. 163 shows the distillatory furnace employed at Idria for obtaining mercury from the sulphuret. The ore is placed in large pieces upon the perforated arch *nn'* immediately above the furnace; the arch *pp'* is covered with smaller pieces, and above *rr'* the powdered mineral and the residues from former operations are placed in small earthenware dishes. A powerful fire is made under the lowest arch, the flame and products from which pass through the several layers of mineral, while currents of air from the channels *H*, *G*, penetrate the walls of the kiln and oxidize the sulphur which is in combination with the mercury. The metal thus liberated passes over in the form of vapour by the flues *ss'* and is condensed in a series of chambers *ccc*.

FIG. 163.

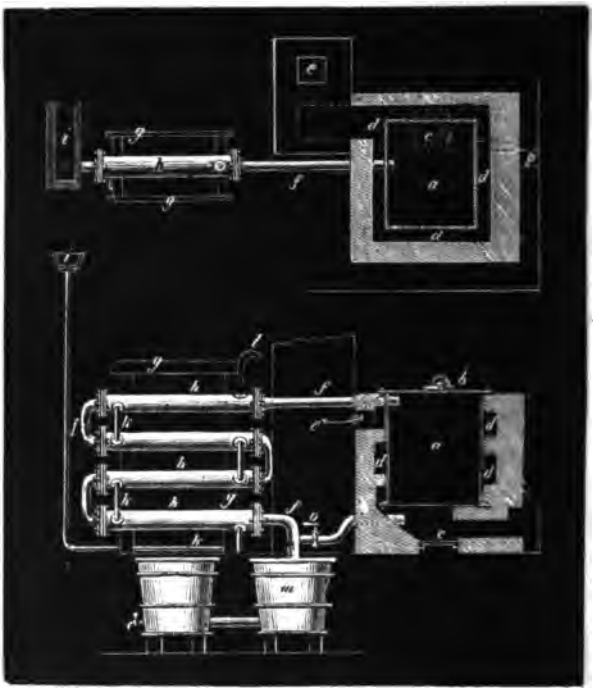


Destructive Distillation.—Distillation is carried on to a great extent with substances which are decomposed in the process for the sake of the products. Sometimes the residue which is left after the removal of the volatile products is the aim of the operation. This is the case with all the processes of charring which have been described in the previous pages, and where in many instances the volatile products are not collected. When the volatile products have sufficient commercial value to repay the cost of condensing apparatus, the operation of charring is conducted in close vessels, and becomes a process of dry or destructive distillation. The nature of the substance, the mode of conducting the operation, and the character of the products, vary so much in these processes, that no general rules can be laid down for the construction of apparatus, which must therefore be looked

for in other parts of this work, where the several branches of manufacture involving dry distillation are described.

Fig. 164 represents the system adopted abroad for distilling

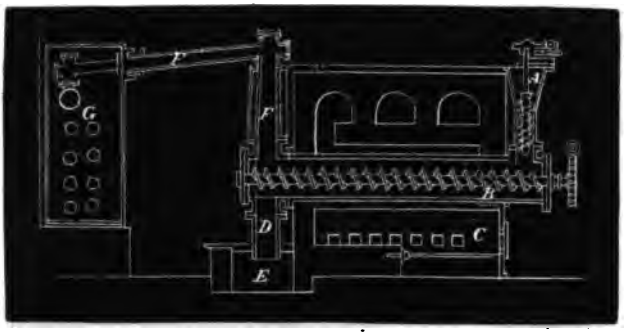
FIG. 164.



wood for the production of tar, pyroxylic spirit, and wood-vinegar. *a* is a strong wrought-iron box with an air-tight lid *b* set over a fire at *c*, the flames from which circulate round the sides of the box in the flues *ddd*, escaping at *e* to the chimney. The products of distillation pass off by the pipe *f*, which is surrounded by a wider pipe *hh* in several of its bends, through which a current of cold water is flowing in the opposite direction to the volatile products in the inner pipe. Cold water is supplied at *i*, and passing from one pipe to the other by the connecting pieces *k*, passes off at *l*. The gaseous products of distillation, which are valueless as illuminating agents, are conducted to the fire by the cock *o*, where they evolve considerable heat in burning, while the condensed products are collected for purification in the vessels *m*. In this arrangement, the process must be interrupted with every fresh charge of material in the box *a*.

Fig. 165 represents the close retorts recently invented by

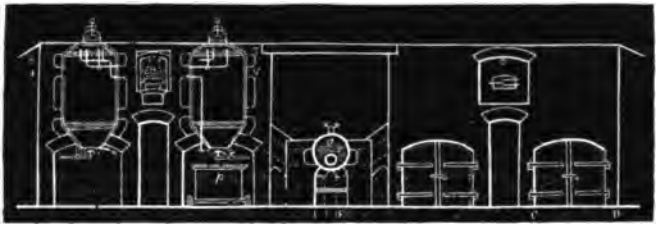
FIG. 165.



Halliday for the distillation of refuse sawdust, tan, dye-woods, and other ligneous matters which are necessarily in the state of coarse fragments or powder. The process of distillation is continuous, a constant supply of material being introduced by means of a screw into the front part of the retorts, and the residuary charcoal discharged in a similar manner. The retorts are in the form of cast-iron cylinders arranged over furnaces in a manner similar to that adopted in gas-works, the screws by which the material is made to travel from the front to the back of the retort being of nearly the same diameter as the retort itself. Each retort is furnished with a wide pipe at the back, the lower extremity of which dips below the surface of water contained in a tank into which the charcoal falls, while another pipe carries away the volatile products to a condenser.

Heated steam has been proposed as the source of heat in certain processes of destructive distillation. Thus, for distilling turf or peat, the apparatus sketched in Fig. 166 has been patented by Vignoles.

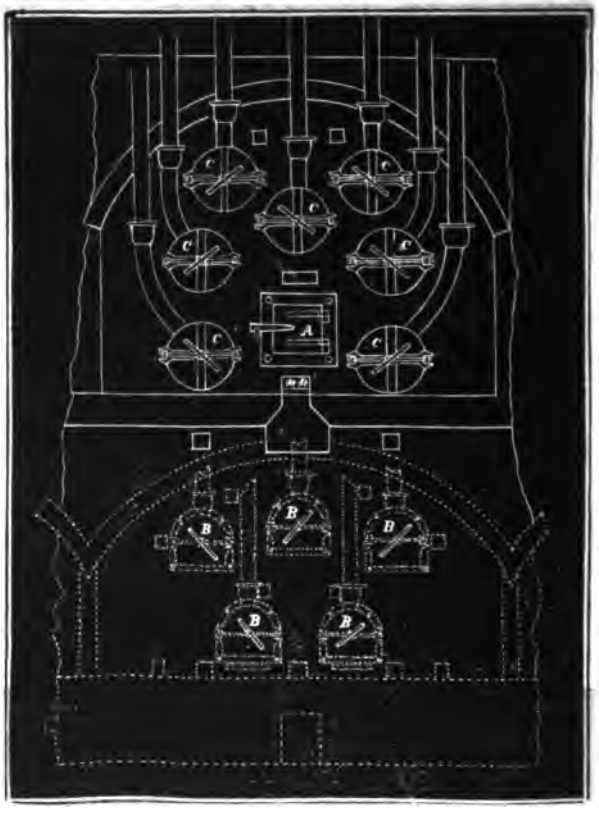
FIG. 166



The steam generated in the boiler *a* is heated to a high temperature by passing through a series of pipes *H*, which are placed in a separate furnace, and is conveyed to a number of cylindrical vessels containing the peat, which are also heated by the waste heat from the boiler furnace. The volatile products from the peat are carried away by the steam and condensed in suitable apparatus, while the charcoal is discharged from the bottom of the cylinders into trucks placed below them.

The most economical arrangement for distilling coal for the manufacture of gas is shown in Figs. 167 and 168.

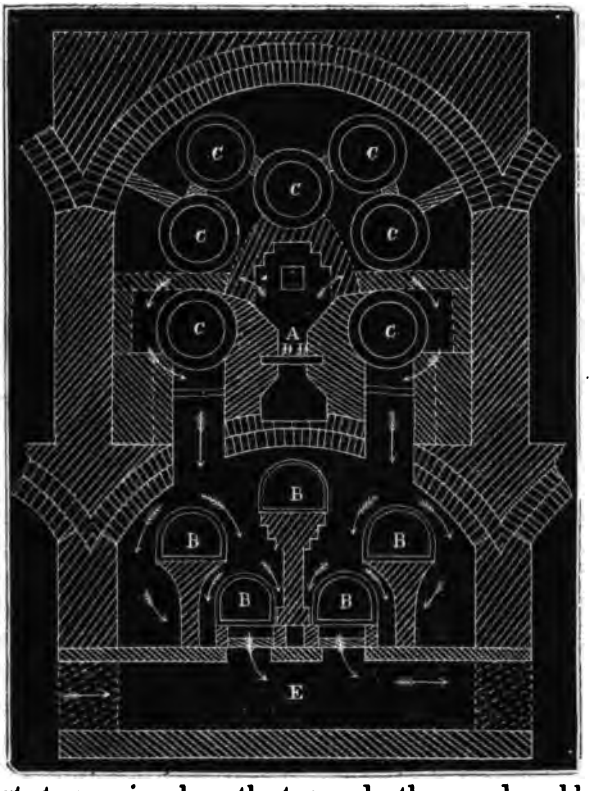
FIG. 167.



CCC represent seven cylindrical clay retorts arranged round the common furnace *A*. These receive the direct heat from the fire; the hot gases, passing by flues in a downward direction, as

indicated by the arrows, Fig. 168, subsequently heat five cast-iron retorts *BBB* situated below the furnace, before escaping to the chimney by the flue *E*. The volatile products of the distillation escape by the pipes shown in Fig. 167 from the necks of

FIG. 168.



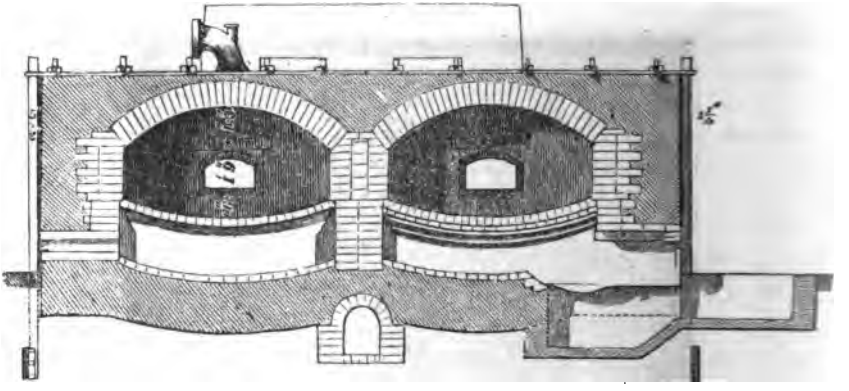
the retorts to a main where the tar, and other condensable products, are partially collected; and they are subsequently passed through extensive condensers to separate the liquid products completely from the gases.

Distillation is sometimes carried on in a vacuum, when apparatus similar in principle to that described under Evaporation is employed, proper measures being taken to condense and collect the vapour; and this has been applied in a modified way to the manufacture of coal-gas.

When the substances to be distilled require a very high temperature, which metal vessels are unable to withstand, fire-brick

ovens are employed. This is the case with pitch, which is distilled in the ovens shown in Fig. 169, a full description of which

FIG. 169.



will be found at a subsequent page, under the Secondary Products obtained in the Manufacture of Gas. The furnaces and flues are below the ovens, the smoke passing by an underground flue to the chimney. The cast-iron pipe through which the volatile products escape is shown at the top of one of the ovens.

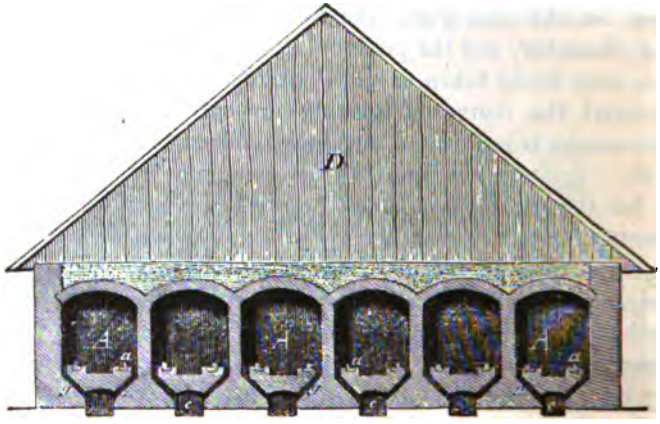
Drying.—The removal of the last portions of moisture from manufactured goods is an operation necessarily connected with the application of fuel, in all those countries at least where the climate is changeable, and simple exposure to the air and sun cannot be resorted to, or are insufficient for the purpose. Indeed, so irregular and uncertain is the system of open-air drying, that it is not adapted for manufactures, where definite quantities of goods are produced every week throughout the year. A current of warm air is generally considered the most effective drying agent, the apparatus for heating the air being placed either outside the drying chamber, or in the interior. From the known quantity of aqueous vapour which air is capable of taking up at different temperatures, and the amount of moisture to be expelled in a given time, the quantity of air to be supplied in each special case must be calculated, the size of the drying-chamber and the diameter of the vapour chimney being adapted to the size of the heating apparatus and the amount of fuel consumed. When the substances to be dried are of such a nature as to remain uninjured by the air, which has passed

through the fire, and is mixed with carbonic acid gas and more or less smoke and dust, the fire may be made below the drying chamber, and the products of combustion allowed to pass into it, care being taken to place the fire at a sufficient distance to prevent the danger of igniting the substances to be dried. Where smoke is prejudicial, anthracite and coke may be employed as fuel.

In far the greater number of drying operations, however, the products of combustion, and the dust and ashes with which they are necessarily mingled, are highly injurious, and hot-air stoves, or pipes conveying steam or water, applied in the manner described in the foregoing sheets, must be employed for heating the current of air. The drying-house should be constructed of badly conducting materials to prevent loss of heat by the walls, and contain no permanent apertures but those for the entrance and exit of the air current, the doors for the introduction of the goods being securely closed during the operation. The size of the drying-room should be so proportioned to the work to be done, that the air at its exit is completely saturated with moisture, and the substances so arranged as to expose the greatest possible surface to the air current, while no air saturated with moisture is allowed to remain stagnant in any part of the chamber. From 7 to 10 feet is found a convenient height for the chamber, and a very great advantage is gained by causing the hot air current to enter at the upper part, and escape from the level of the floor. The velocity of the current is thus retarded, and time allowed for its perfect saturation, while partial currents and consequent stagnation in certain regions of the chamber are avoided, which almost invariably occur when the current passes rapidly in an upward direction. Several vapour chimneys for discharging the saturated air, often produce a better distribution of the hot current than a single vent, and it is frequently necessary to cap them with a moveable cowl, which, turning with the wind, allows the vapour to escape more easily. The draught may often be secured and augmented by connecting the vapour discharger with the chimney of the heating apparatus.

Fig. 170 shows a series of drying chambers employed for drying wood for the use of glass houses in France. The six chambers *A A A*, are each 60 feet long, 6 feet broad, by 5 feet high; they are arched over, and the whole covered by a single roof. There is a fire at each end of every chamber, and the

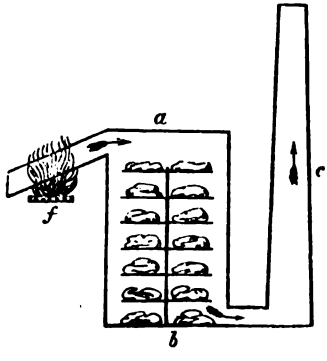
FIG. 170.



products of combustion are allowed to enter by the passages *g g* into the body of the kilns at some distance from the grates. The wood to be dried is placed upon trucks, which travel on the rails *a a*.

The system usually practised by bleachers and others in this country for drying their goods, is by an intermittent saturation of the air contained in the drying chamber. The chamber is built over a furnace, the metal flue from which extends through its entire length. The goods being introduced, the chamber is kept carefully closed until the air has become saturated with moisture, which may be observed by a window in the side becoming distinctly covered with dew. The door and louvres or shutters in the top are then opened, when the moist air is discharged, and a fresh supply admitted. This operation is repeated until the goods are sufficiently dry. This is a very simple method, but it involves a considerable loss of heat, while the goods are not perfectly dried.

FIG. 171.

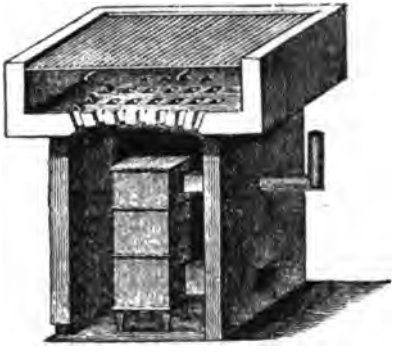


The principle upon which the common madder stove is constructed is shown in Fig. 171, and is far better calculated to make full use of the hot current of air and completely dry the matters exposed. Into the close chamber *a b* hot air is admitted

at the top, where it meets the sacks filled with roots, which have been successively moved from shelf to shelf, beginning with the lowest; on reaching the top, they therefore contain but little moisture, and the current of hot air, being comparatively dry, soon removes the last portions, and becomes saturated by contact with the moist sacks before leaving the chamber by the chimney *C*.

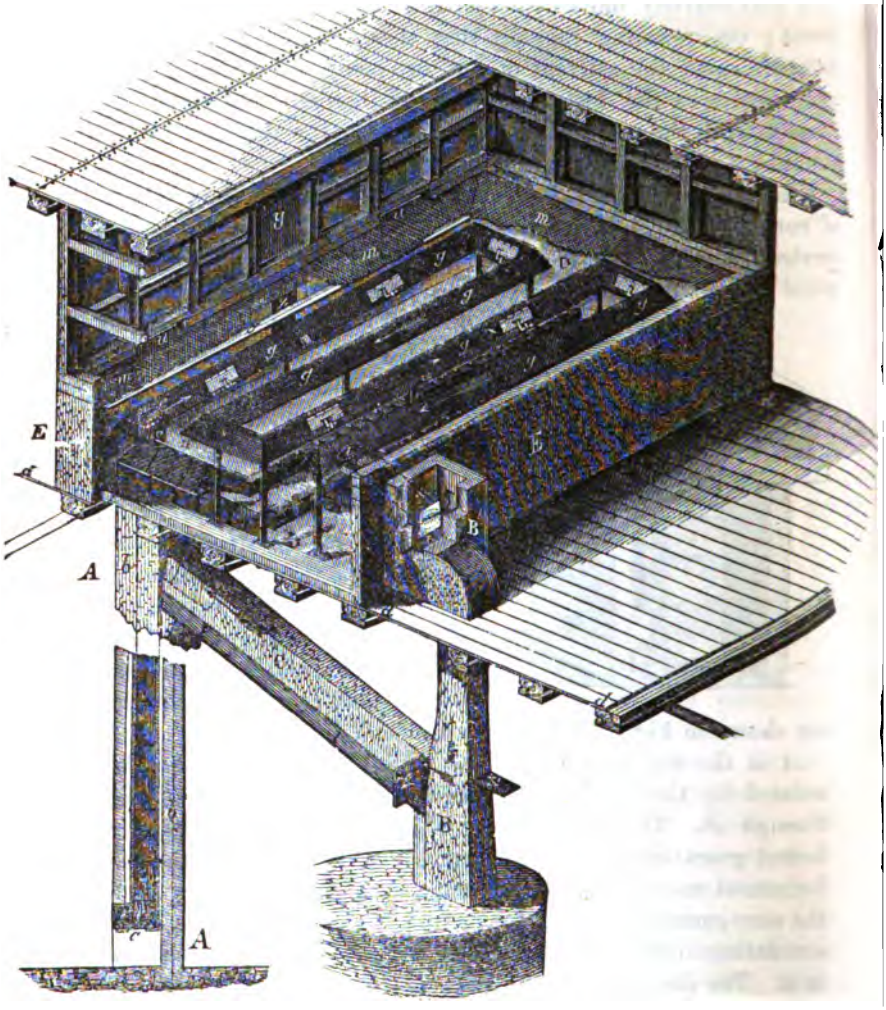
Kilns are employed for drying malt, into which the products of combustion from a charcoal, coke, or anthracite fire are carried, with a large body of warm air, through a perforated metal floor, upon which the malt is lightly spread out. Sometimes a current of warm air only is employed, while the smoke and heated gases from the fuel are removed by a flue. This arrangement of the malt-kiln may be seen from Fig. 172, where the air, heated by the stove, ascends through the perforations in the floor above it, upon which the malt is placed. In the large breweries of Bavaria the malt is dried in the manner shown in Fig. 173, by warm air.

FIG. 172.



A is the fire for heating the drying floor, which is often assisted by the waste heat from the boiling-furnaces supplied through *B*. The iron cylinder which conveys the smoke and heated gases from the fire, communicates with the triangular horizontal metal flue *g g g*, passing in a zigzag manner under the wire-gauze floor *m m*, upon which the malt is placed. After circulating in this flue, the smoke escapes through the chimney at *B*. The dampers *x* and *x'* in the flue *B* enable the smoke from the boiling-furnaces to be carried either directly to the chimney or through the flue *C* to the malting-floor. Air enters the flue *b b* which surrounds the smoke-pipe *a*, and is conducted by a series of half-open channels, constructed with bricks, on the floor of the drying-chamber, below the horizontal flue *g g*. These channels are higher on the one side, and covered with tiles in a slanting direction, to prevent any particles of malt from falling into them. The air thus warmed by contact with

FIG. 173.



the smoke-flue, passes through the malt and dries it. The wire-gauze bottom, over which the malt is spread out, is supported by bars of iron.

The methods of drying manufactured goods by exposure to the radiant heat of surfaces, through which smoke or steam is passing, and the centrifugal application now so universally employed, involve no novel application of fuel.

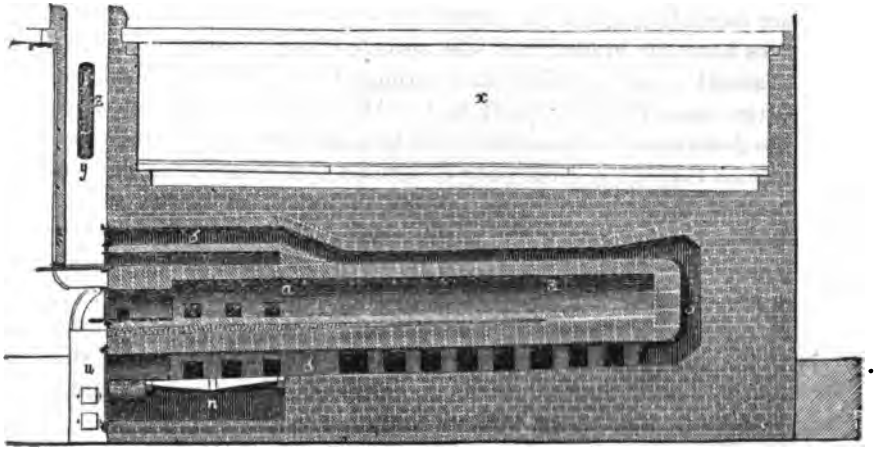
Baking, Annealing, Calcining, &c.—Ovens and kilns are used for a great variety of purposes in the arts, and are modified in form and construction to suit the different objects in view.

In some operations, it is necessary carefully to separate the objects to be baked or heated from the fuel and products of combustion; while in others, the contact of these with the fuel and smoke is attended with little or no inconvenience, and sometimes is even absolutely necessary. Most of these operations differ from simple processes of drying, by the change of chemical composition which the high temperature employed induces in the objects exposed to it.

The ovens employed for baking bread are still very commonly heated by wood, which is placed upon the sole of the oven itself, flues being introduced at the back for carrying away the smoke. When the charge of wood is completely consumed, these flues are stopped by dampers, and the ashes are removed. The bread is then introduced, and the oven closed, the accumulated heat in the brickwork being sufficient to bake the bread. The operation is in this case necessarily interrupted each time a baking is completed, and coal should not be employed as fuel, on account of the dirt it produces, although the flame from a coal fire is still often admitted to heat the oven.

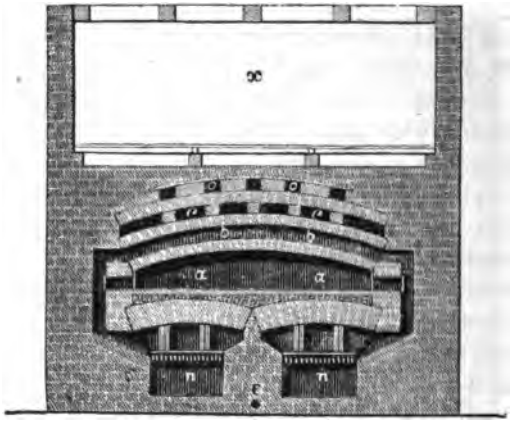
Figs. 174 and 175 show sections of a large oven, in which the

FIG. 174.



fuel is not admitted into the interior, and which admits of an uninterrupted process. Coal is burnt on the grates at *n n*, and the smoke and heated gases from its combustion passing through a series of arched flues below the sole of the oven *a a*, return again by the flue *b* over the top to the chimney *y*. In the front of the oven, which is less exposed, distinct flues convey a portion of the flame into the oven, or over it, as may be required, while a series of pipes in connection with the flues *o o* carry off the vapour rising from the loaves in baking.

FIG. 175.



In baking porcelain and pottery, a very high temperature is required, while the objects exposed to it must be carefully protected from the smoke and dust of the fuel.

Figs. 176 and 177 show the construction of a porcelain kiln. Four separate fires *A A A A* discharge the flame and products of combustion into the body of the kiln *L L'*, in which the goods are carefully packed in protecting vessels called seggars. The fires have no grates, but the space *e* being filled with red-hot charcoal, wood is introduced through the aperture *b'*, until the entire space *f* is filled with fuel. Air is supplied through *b'* in the downward direction indicated by the arrow, and has therefore to pass through a great body of ignited fuel before reaching the body of the kiln; cold air is thus excluded, and more perfect combustion secured. The flame is separated into three distinct portions, passing through the flues *p p p*. The different stages in the kiln *L L'* and *G* are connected by numerous apertures *t t t*. In the lowest, where the greatest heat prevails, the final baking of the ware is effected; while the upper stories are used in the earlier parts of the process of manufacture. For further details, we refer to Vol. II. of "Chemical Technology."

FIG. 176.

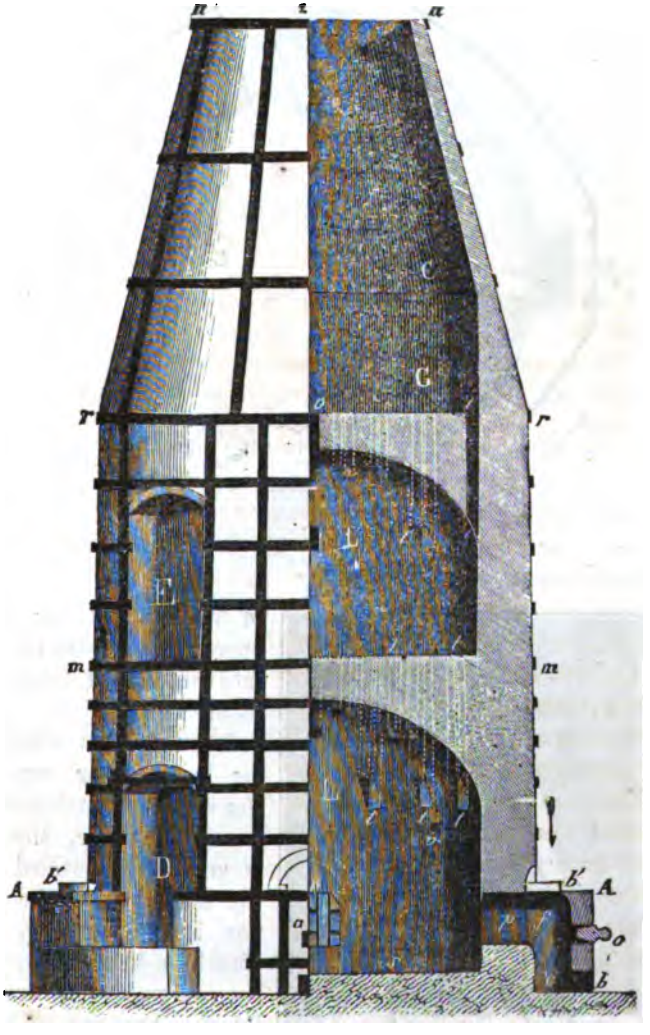


Fig. 178 represents the kiln employed for baking stoneware in the Lambeth potteries. Coal being the fuel consumed, a slanting grate, shown at *c*, is employed, which is fed from above in such a manner that the air is forced to pass through and over the burning fuel. Five of these grates are placed at equal distances round the body of the kiln, a perforated chimney, or *bag*,

FIG. 177.

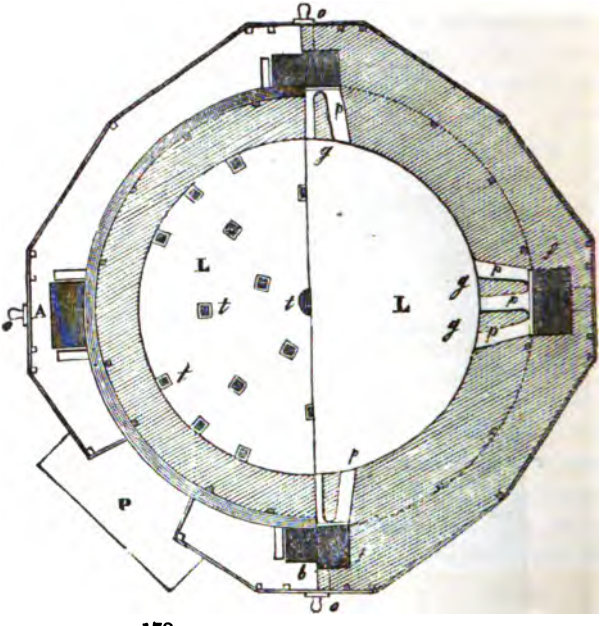
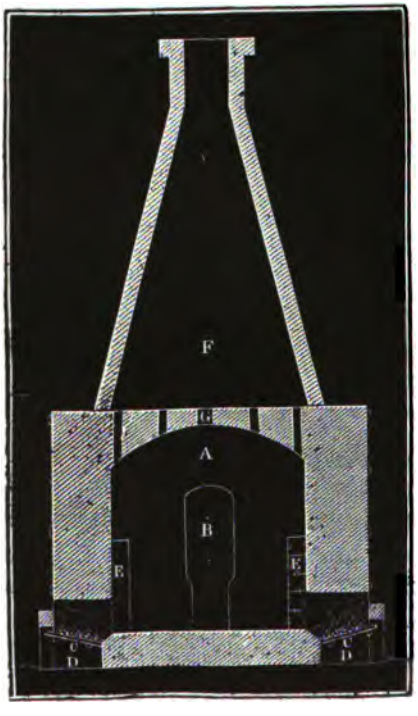


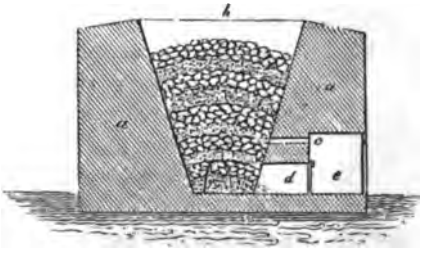
FIG. 178.



of brickwork, being placed opposite each fire to separate the flame at its entrance to the kiln.

In the kilns employed for burning or expelling the water and carbonic acid from lime-stone, the fuel is generally stratified with the lime-stone in the manner shown in Fig. 179. The kiln being once fired, the combustion is kept up by the consecutive layers of coal, and the lime is drawn at intervals from the bottom of the kiln. Where wood and turf are employed as fuel, an arrangement similar to that employed in the potter's

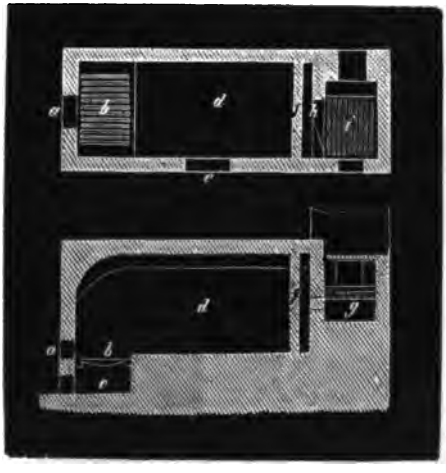
FIG. 179.



kiln is adopted, as may be seen by reference to Vol. II., p. 382.

Schubarth's oven for calcining bones and producing animal charcoal is shown in Fig. 180. *a b c* represent the fire-grate and ash-pit; *d*, the body of the oven for the bones, which are placed in earthenware pots, and weigh from 1 to 2 tons per charge. The opening *e* in the side of the oven is walled up during the operation. *f* is a partition wall at the end, with several openings, something like the fire-brick ovens, and communicating with the ash-pit *g* by means of the flue *h*.

FIG. 180.



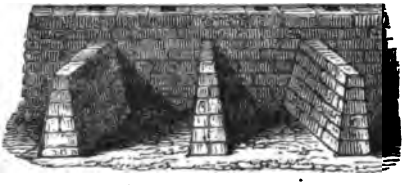
The offensive gases which arise from distilling bones, pass off through these openings, and are consumed by the fire on the grate *i*, while the heat is employed for drying the prepared charcoal. In some cases, in France, the waste heat from four such ovens is employed for re-burning the spent charcoal.

Furnaces.—The furnaces employed for the various purposes of metallurgy, &c., are essentially of two kinds: first, those in which the fuel is brought into direct contact with the substance to be operated upon; and secondly, those in which the flame only is employed. Both may be aided by an artificial blast of air.

To the first class belong the furnaces employed in many countries for roasting ores, which are in every respect similar in principle

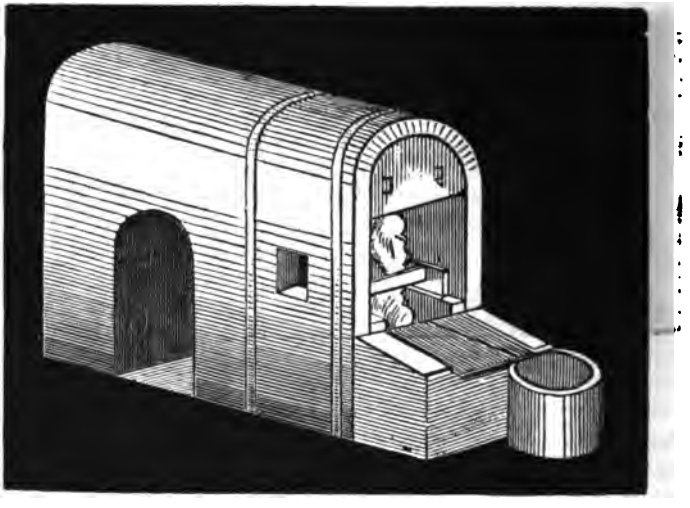
to the lime-kiln described above. The same operation is sometimes carried out in ore kilns when the mineral is of such a nature as to continue the combustion spontaneously which has been once commenced. Thus, Fig. 181 shows the simple kilns on which copper pyrites and the products from the first fusion of the ore, called matt, are calcined or roasted, being placed upon a bed of brushwood, which, when ignited, sufficiently heats the ore to enable the bituminous matter contained in it to continue a slow process of combustion. The vacant spaces in the walls tend to increase the draught.

FIG. 181.



A smith's forge is, perhaps, the simplest adaptation of a blast to increase the temperature of fuel for working metals; a current of air being thrown by a bellows into the fuel where it is in contact with the metal to be heated. Much of the lead-ore in this country is melted and reduced in a furnace constructed upon similar principles, and called an ore-hearth. It is shown in Fig. 182, as improved by Dr. Richardson.

FIG. 182.

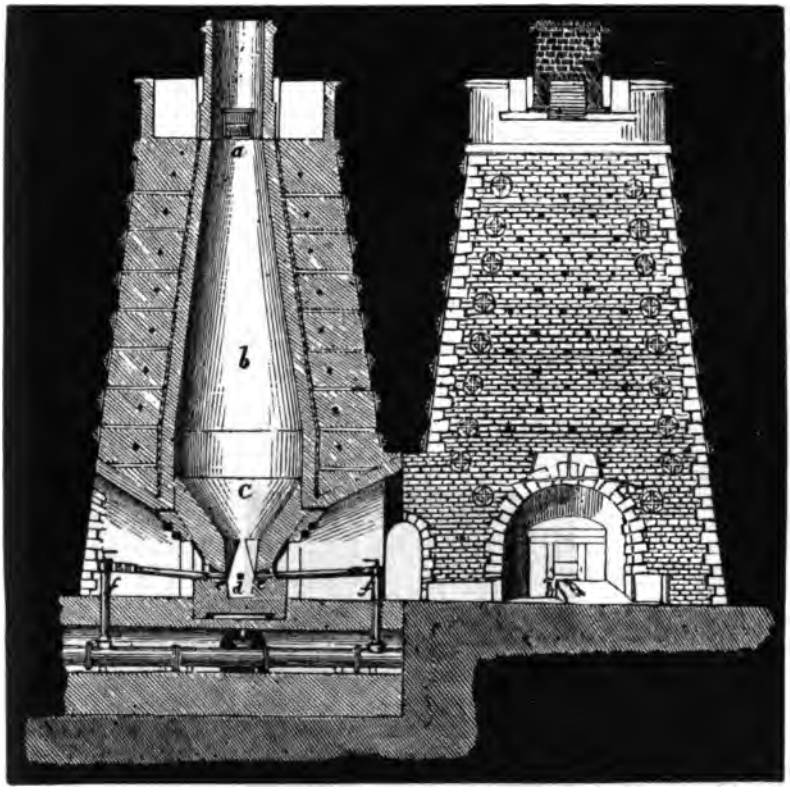


The blast enters from behind, and the flame and lead smoke, termed *fume*, are seen escaping over a bridge into a main flue at

the back. The lead-ore is thrown in through an opening at the side, with peat, or coal. The temperature is not very high, and is easily regulated. Great economy of fuel is secured by the use of this kind of furnace, which is, however, only adapted for rich lead-ores.

The English iron blast furnace is represented in Fig. 183 in section, and by a front view in Fig. 184. The materials are thrown in at the top *a*, and gradually descend through the body

FIG. 183. FIG. 184.



of the furnace *b*, to the boshes *c*, while the metal accumulates in the hearth *d*. The blast of hot air enters the furnace through the tuyeres *e*, which are connected with the pipes *f*, from the heating stove. The effect of the hot air on the materials is well illustrated in the following drawings, Figs. 185 and 186, which also serve to explain the variations in the composition of the

gases drawn from different depths in a blast furnace, as also the different temperatures in the different zones.

In that part of the furnace denoted as the region of combustion, abundance of hot air is supplied by the blast, and the carbon and hydrogen of the charge are converted into carbonic acid and aqueous vapour respectively; these gases ascending through the fusing and carbonising regions, meet with a large quantity of carbon at a very high temperature, and are converted into carbonic oxide and hydrogen, which then react, in the region of reduction, upon the oxides of iron, converting them into metal, and escape again from the mouth of the furnace partly converted into carbonic acid and steam. The reduced iron is unable to melt at the temperature of the region of reduction, but descending into regions where the heat is stronger, and carbon still abounds, it combines with the latter, and is converted into the more fusible carburet, which collects at the bottom, whence it is withdrawn at intervals.

FIG. 185.

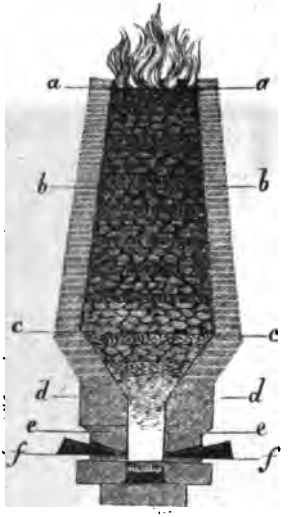
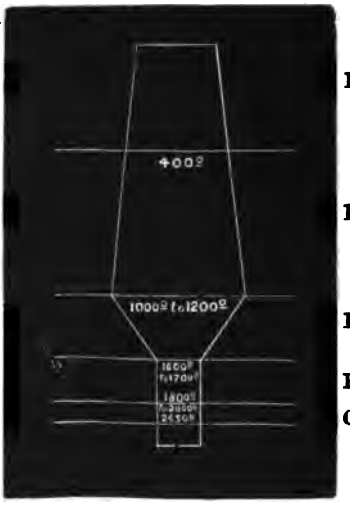


FIG. 186.



Richardson's furnace, Figs. 187, 188, and 189, for treating silver residuums from zinc-ores, &c., &c., will furnish another illustration of the application of the blast.

a is the body of the furnace, formed of single brick, and the bottom of clay and finely ground coke, well beaten down, and cut into the form shown in the annexed sketch. The materials are thrown into the furnace by the charging door *b*, and a fine

FIG. 187.

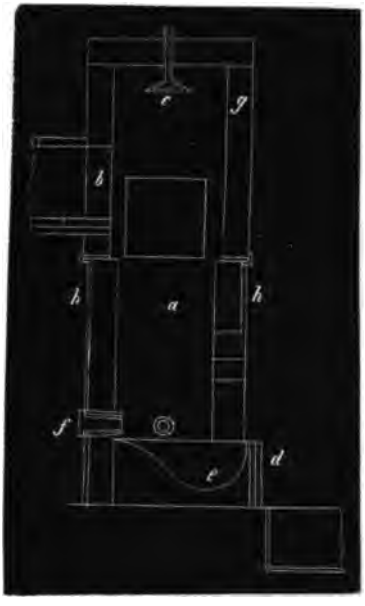


FIG. 188.

FIG. 189.

spray of water made to play upon their surface from a rose situated at *c*. The front of the furnace is supported by a metal casting *d*, over which the slag flows either into water or into metal tubs. When the silver-lead has accumulated in sufficient quantity in the hearth, it is tapped into a pot at the point *e*. The furnace may be worked by means of a blast thrown into the furnace by the tuyeres *f f f*, or by increasing the number of these openings to five or six, and connecting the

furnace with a tall chimney, when the natural draught will be sufficient. The upper portion of the furnace *g* is supported on four metal pillars and binders, *h h h h*, which remain untouched on renewing the lower part of the furnace after being worked out.

Furnaces in which the flame of the fuel alone is employed, are called reverberatory furnaces. The fuel is burnt upon a grate, and the flame is drawn by a powerful chimney draught over the substances to be heated, which are inclosed by a more or less elevated arch of brickwork. These furnaces are frequently constructed in two flats, as shown in Figs. 190 and 191, where

FIG. 190.

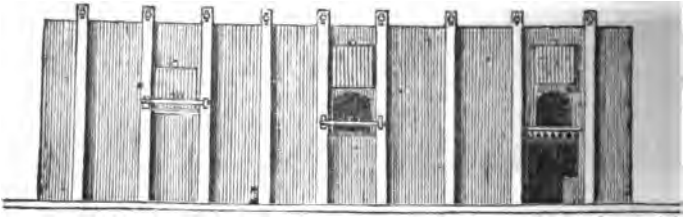
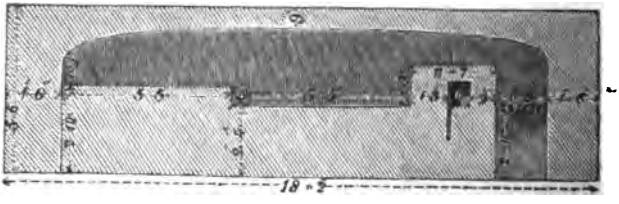


Fig. 190 shows an elevation, and Fig. 191 a longitudinal section of the furnace. The charge in many instances is introduced on to the higher flat, which is further removed from

FIG. 191.

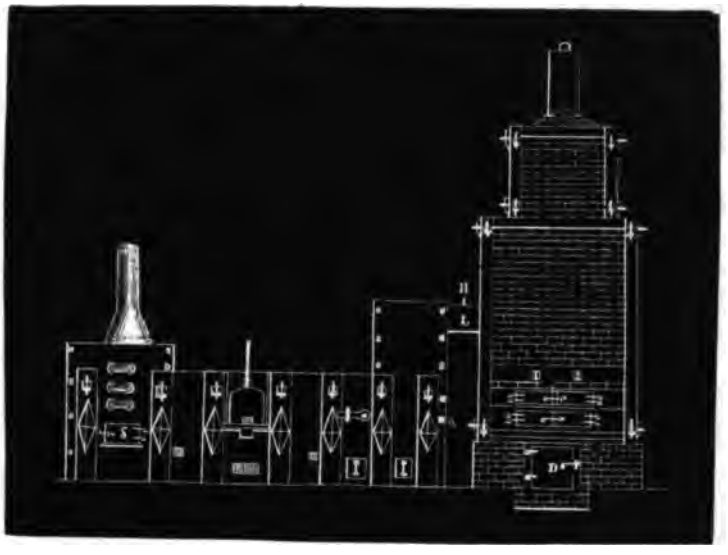


the fire, and subsequently raked down on to the lower level, where it is exposed to the full heat of the flame. Furnaces of this description are employed in the manufacture of carbonate of soda.

The gaseous combustibles from the generators described at pages 154 and 156, have been employed in the reverberatory furnaces for producing wrought iron, commonly called Balling or Puddling furnaces. The mode of application is shown in Figs. 192 and 193.

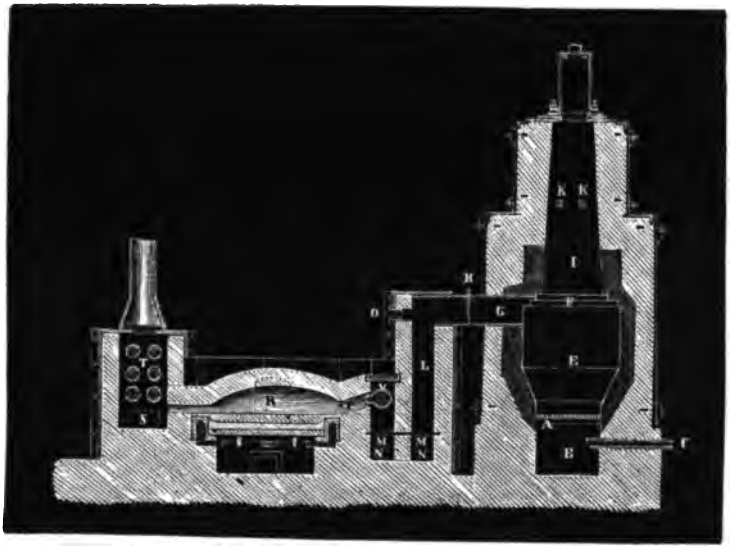
The gas-generator consists of the grate, ash-pit, and door

FIG. 192.



a, *b*, and *d*, while the air is supplied through a tube *c*. The space *e* is filled with red-hot fuel, where the carbonic acid is converted into carbonic oxide. The gas accumulates at *f*, and

FIG. 193.



is conveyed away by the flue *G*, in which a damper *H* is placed. The shaft *i* is wider at the bottom, which prevents the fuel hanging to the sides, and is furnished with two small openings *k k*, by which the height of the fuel is observed, or through which it is broken up from time to time. The other details are fully shown in the drawing.

In the present application, the gas passes through the flue *l* into a chamber *m*, where the dust and mechanical impurities are deposited, which are removed at intervals through the openings *n* or *o*. The gas is not ignited immediately as it issues from the nose-pipes, but passes over a bridge *p* into the hearth of the furnace *r*.

The blast is partly heated by a small fire at *s*, and partly by the waste gases passing round the pipes *t*, which communicate with the pipe, *v*, extending the whole length of the gas-flue, and which is furnished with 7 to 11 nose-pipes. Those gases which contain least aqueous vapour are most easily ignited, and produce the greatest heat.

The temperature required for the conversion of cast into malleable iron is very intense, and is obtained by the consumption of a very large amount of fuel in the puddling furnace, where the draught is produced by a chimney not exceeding 35 feet in height. Mr. Prideaux has shown, in the Treatise on Fuel before alluded to, that it is a very extravagant application of fuel, to employ it for the production of a powerful draught by means of the ordinary chimney, and that much greater heat would be obtained from a small proportion of the fuel now consumed, if it were used to raise steam for driving a fan, by which heated and compressed air could be supplied to the ash-pit. The ash-pit must then, of course, be closed, with the exception of the tuyeres for the admission of the blast. An ample supply of hot compressed air to the interior of the furnace would also be very advantageous, in preventing the influx of cold atmospheric air through the working-holes and the crevices of the brick-work, which must, on the present system, tend to lower the temperature very materially.

Figs. 194 and 195 represent an extraordinary combination of bottom and surface heat for decomposing common salt. In the section, *c* represents an iron pan, heated from below by a fire *d*, from above by those at *e e*. The drying flats *f f* are separated from the pan by brick partitions, and communicate by means of

openings at *g g*, which may be closed with dampers. The bulk of the muriatic acid escapes at *h*, when intended for the manufacture of chloride of lime, and what is retained by the partially manufactured sulphate at *i i*. The working-doors are shown at *k k k*; the underground recess for stoking the fire by *l*, which is covered by trap doors *m m* during the decomposition of the common salt.

FIG. 194.

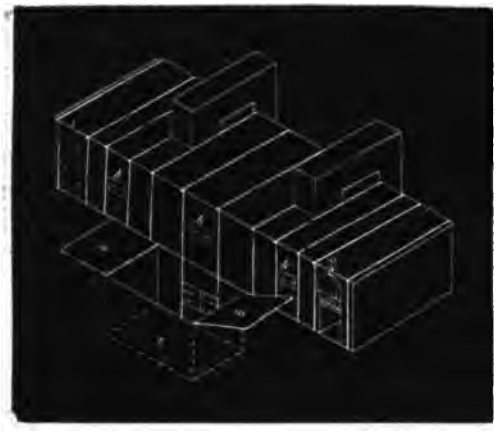


FIG. 195.

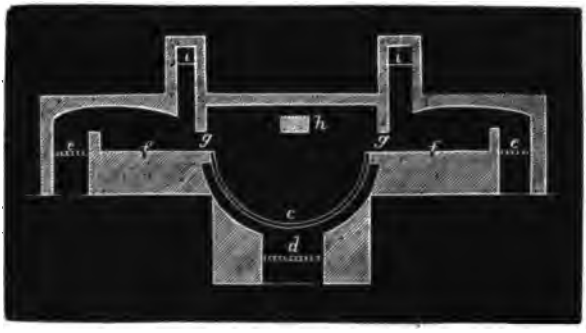


Fig. 196 is a ground plan of a smelting furnace for lead ore, which shows the peculiar manner in which the bottom of the furnace slopes to one point, so as to allow the lead to run off as it is produced. The arch is very low, and throws the flame down on the ore in a manner peculiar to this operation.

The furnaces employed for the refinery of silver may be worked by an ordinary blast, but a steam-jet employed as shown in Figs. 197 and 198 has been found to answer equally well. The fuel is thrown into the fireplace *a*, and the flame passes over the bone-ash test *b*, which serves the double purpose of forming the bottom of the furnace and a bath for the molten lead. The lead is run into the test from a pan *c* through a

FIG. 196.

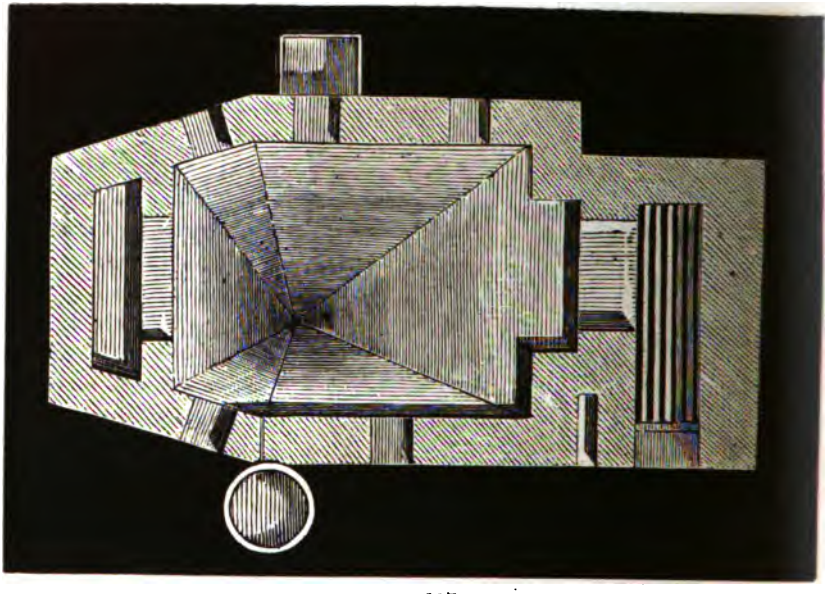


FIG. 197.

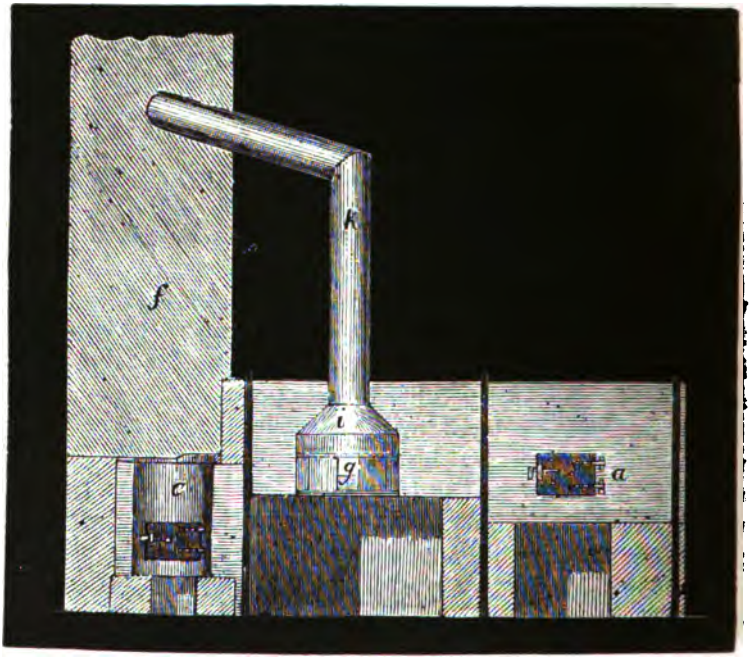
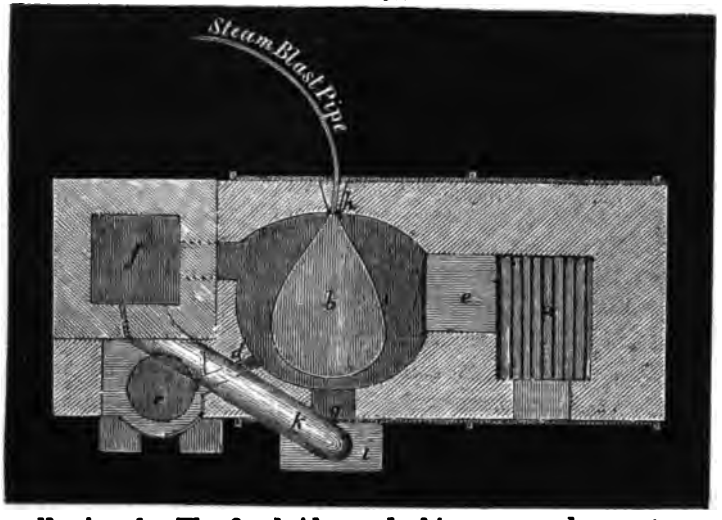


FIG. 198.



small pipe *d*. The fire-bridge and chimney are shown at *e* and *f*. A small door *g* allows the workman to inspect the progress of the refining, the state of the test, and to facilitate the overflow of the oxide of lead, as it is formed and blown forward by the air and steam-jet entering at *h*. The iron hood and pipe, *i k*, serve to convey any metallic fumes which escape during this inspection to the chimney or main flue.

As the last illustration of the application of fuel in metallurgical operations, Fig. 199 represents the furnace employed in Belgium for the reduction of zinc ores. The furnace is in the form of a rectangular prism, in which are ranged altogether about 46 clay tubes, in 8 rows, inclined towards the front of the furnace, where they deliver the volatile metal into cast-iron pipes, and thence into sheet-iron receivers. The single fire is placed at *A*, and the flame plays round all the clay vessels, which are charged with roasted ore and charcoal.

FIG. 199.

Of the Actual (Practical) Effect of Fuel.—It has already been repeatedly mentioned, that the effect of fuel in practice is very much below what it should be according to theory. The causes of this are partly fortuitous; partly, however, pertain to the nature of the process, and are consequently unavoidable. The absolute necessity for the maintenance of a draught in the chimney, to which a portion of the heat evolved must always be sacrificed, is one of the more important sources of loss.

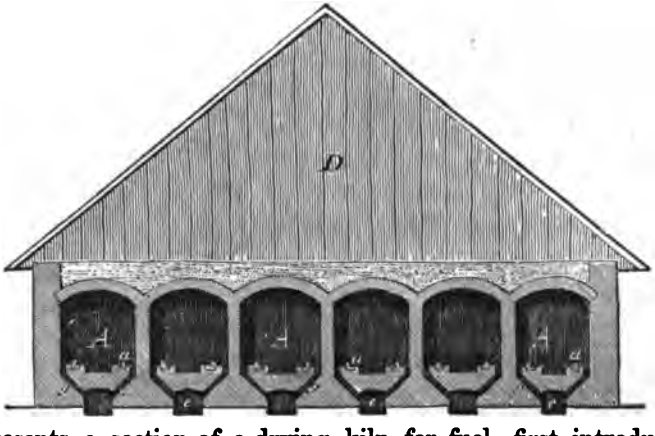
By reference to a former page, it will be seen that 1 lb. of dry wood requires on an average 5.94, or in round numbers 6 lbs. of air of 0° (=148 cubic feet) for perfect combustion: suppose this air to escape with a temperature of 150° C. into the chimney, the quantity of heat then contained in it will be as great as that contained (in 1 lb. of air at $6 \times 150° = 900°$ or) in 9 lbs. of air at 100°, and consequently in $\frac{9}{8.746} = 2{,}4$ lbs. of water at 100° C. According to Schödler and Petersen, 1 lb. of dry wood will heat on an average 40.6 lbs. of water to 100°,: the action of the chimney, therefore, causes a loss of $\frac{2.4}{40.6} = 0.06$, or 6 p. c., which loss increases with the temperature of the escaping air.

A portion of the fuel is also prevented from combining with oxygen and evolving heat by the lowness of the temperature in the immediate vicinity of the sides of the fireplace, and at least twice as much air as is theoretically required is generally admitted, which also diminishes the temperature, while the occasional obstructions to the proper access of air through the grate bars farther lessen the efficacy of the fuel. These impediments to perfect combustion cause a portion of the fuel to be converted into volatile or non-volatile products, which are mechanically carried away by the draught to the remoter parts of the chimney, where they pass off as *smoke*. The smoke is still capable of uniting with oxygen, and of evolving a quantity of heat equivalent to that portion which is lost. The combustion in the fireplace is therefore a partial process of dry distillation: instead of the vapour of water, carbonic acid and nitrogen being the only products, these gases constantly pass off mixed with smoke, which partly collects as *soot*. The smoke-consuming arrangements in stoves affect to burn the smoke by bringing it into contact with a stream of hot air. The condensable portions of the smoke, as well as the water formed during combustion,

absorb heat in being converted into vapour, which heat is, for the most part, lost. The loss occasioned by the hygroscopic water, from which fuel is seldom free, is still greater. In the first place it diminishes the weight of the combustible; 1 cwt. of wood, for instance, only containing 80 lbs. of actual fuel, and secondly, the water absorbs a large amount of heat in being converted into vapour. For this reason Rumford's experiments (with common wood) give a less result than those calculated from the analyses (with dry wood); although the heat of the vapourized hygroscopic water is not lost in the calorimeter, as it is in practice, being in the former case condensed again into water. Wood, in the ordinary air-dried condition, contains about $\frac{1}{4}$th water, and only $\frac{1}{5}$ths of actual fuel; of the 40.6 lbs. of water, which 1 lb. of dry wood heats to 100°, $\frac{40.6}{5}=8.1$ lbs. are left cold; besides, every $\frac{1}{4}$th lb. absorbs as much heat as corresponds with $\frac{1}{4}\times 5.5=1.1$ lb. of water at 100°. Altogether, therefore, the moisture in the wood causes a loss of heat $=\frac{8.1+1.1}{40.6}=$ 22$\frac{1}{2}$ p. c.

This clearly explains the economy of dry fuel. For domestic purposes it is generally too costly, and not practicable, to dry the wood by artificial means; while, for certain applications in the arts, dry fuel only can be employed. Fig. 200

FIG. 200.



represents a section of a drying kiln for fuel, first introduced in the French glass houses. The whole space covered by

a single roof is a long quadrangle, and contains six arched passages *A A A*, 60 feet in length, 6 feet broad and 5 feet high, which may be viewed as separate stoves, each having its own fire *c c c*. Each fireplace extends below the whole length of the arch *A A*, terminating at both ends in a grate, whence the heat is conducted to the middle of the arch, but also freely escapes along the whole length into the space *A* by the several flues *g g* cut in the sides. These flues are further apart in the neigbourhood of the grates, but are more numerous towards the middle, so as to spread the heat more equably. The fires *c c c* are arched over for a short distance, above the two grates; further on, and towards the middle, they are covered with sheet iron. Above is a railway *a a a*, upon which the iron barrows travel, containing the fuel to be dried. The iron plates prevent the flame from igniting the contents of the barrows, each of which contains about two stacks of wood; there are nine barrows in every arch *A*, and the whole charge is dried in thirty-six hours.

Although water has thus been shown to diminish the effect of fuel, this is not invariably the case under all conditions, and a contrary result appears to be produced when the water is brought into contact with the fuel in the gaseous state. The experiments of Bunsen and Fyfe have shown that red-hot coal and aqueous vapour mutually decompose each other into hydrogen and carbonic oxide gases (with some carbonic acid), both of which, if sufficient oxygen be present, burn with the production of a white heat to form water and carbonic acid;* numerous observations showed further, that the additional heat evolved more than compensated for the fuel employed in producing the vapour. If, therefore, sufficient air be present with the vapour to burn the gases which are formed, the vapour will be of service, producing a greater amount of heat and a more lively combustion. The moment, however, that the vapour exceeds the proper proportion, and the supply of air is thus diminished, the temperature rapidly sinks, so that the fire is often totally extinguished.

A common practice is to place a vessel with water under the

* 1 part of coal, burning, surrounded by vapour, first to carbonic oxide and then to carbonic acid, heats 78.15 of water to 100°; 0.1666 parts of hydrogen are liberated at the same time, which, in burning, heat 39.5 parts more water. The advantage gained, therefore, is $= \frac{78.15}{78.15 + 39.5} = \frac{1}{3}$, supposing the combustion of coal in aqueous vapour to be attended by the same heating phenomena as in the air.

grate of the furnace, so that the heat radiating downwards may cause evaporation without cost. In steam engines, a portion of the vapour which has been used may be conducted at once to the fire, instead of being condensed. An addition of water to the fuel causes so great a depression of temperature while the water is being converted into vapour, that the decomposition of the aqueous vapour can no longer be effected, and the practice, which is not unfrequent amongst consumers of coal, is therefore not economical. Practical experiments, instituted by the Frankfort Society for the Improvement of Arts and Manufactures, have also clearly proved the practice to be bad. A moderate moistening of small coal has, however, the advantage of preventing its falling through the grate-bars and creating dust, for it cakes together and becomes more solid by being moistened. It is still better to add about $\frac{1}{4}$th of moist clay for the same purpose, which being disseminated throughout the mass of the coal, affords greater access to the air, and the heat absorbed by the clay, being slowly evolved, acts with more advantage. The experiments made by the Frankfort Society have shown that small coal mixed with clay was even better than small coal alone.

When moist wood is so closely heaped together, that the air cannot pass freely through, a chemical change quickly follows, which is accompanied by the almost entire destruction of its combustibility. It is well known that the dead wood in the centre of old trees (where moisture, but little air, has access), becomes changed into a white, soft, phosphorescent substance, which, when ignited, burns slowly without flame, like tinder, evolving very little heat. During this mouldering process the weight of the wood has undergone greater change than the relative proportions of its elements. A specimen contained, for instance, 47 per cent carbon, and with 6 per cent hydrogen only 45.3 per cent oxygen; this greater proportion of hydrogen than in fresh wood would tend to increase the inflammability of the substance if it were not already chemically combined to form water, a supposition fully borne out by the properties of the substance. Wood thus changed is said to have undergone the *dry rot*.

The heating value of combustibles obtained by careful experiment and calculation is of great importance as a control in estimating the beneficial practical application of fuel, and an indication of what may be obtained. The difficulties in the way

of perfect combustion, however, are so numerous and varied in their source, in the different methods of employing fuel, that no estimation of its value for any particular object can be accurately determined by one method. It has consequently been found necessary to ascertain by direct experiment the relative value of combustibles in the various kinds of grates, fire-places, boiler-fires, &c., which they are intended to supply.

With reference to the warming of dwellings, it was found in a series of experiments,—in which the external temperature varied from $+6.8°$ (44° F.) to $-6.2°$ (21° F.), and the air of the room had a mean temperature of 15 to 19° C. (59°—66° F.), while the smoke escaped by the chimney at a temperature of 75 to 100° C. (167° to 212° F.),—that 100 lbs. of air-dried cleft beech wood effect as much as 48 lbs. of pitcoal, 40 (the smoke being cooled as much as possible) to 60 lbs. of mixed small coal moistened with $\frac{1}{17}$th of water, 44 lbs. of bituminous small coal with $\frac{1}{17}$th water, 37 lbs. of small coal with $\frac{1}{17}$th water and $\frac{1}{3}$th clay, and 38 lbs. of small coal with $\frac{1}{3}$th water and $\frac{1}{3}$th clay. The observed temperature of the air was a mean, existing at an equal distance from the floor and ceiling of the room. The observations prove, that the temperature of a room, after equilibrium has once been established, is highest at the top, and increases for equal distances from the bottom, very nearly in geometrical progression, although the quotient is not the same under all circumstances. In one case it was found to be $=1.0727$, when the temperature increased as follows: floor 18.36; at 2 feet 18.36×1.072; 4 feet 18.36×1.072^2; 6 feet 18.36×1.072^3, &c.

The action of coal under steam boilers has been examined by Fyfe, who believes that the heat actually made available from coal in *practice*, is nearly the same as ought to be produced, according to theory, by the quantity of coke which it yields. If coal produces 50 per cent of coke, for example, then 100 lbs. of the coal would boil 50×78.4 lbs. (Despretz) of water. According to Fyfe, 1 lb. of Scotch coal from Trenant will convert 5.61 lbs. of water into vapour from 0° C.; 1 lb. of the coke from this coal will boil 7.4 lbs. of water: 1 lb. of coal from Trenant yields 0.525 lbs. of coke, which will consequently produce 3.9 lbs. of vapour, so that by carbonization there is a loss of heating power equivalent to $5.61-3.9=1.71$ lbs. of vapour. In other experiments the results with coal were 5.8 and 6.6, and with coke between 7.8 and 8.7. The greatest effect observed by

Parkes was 8.68 lbs., and by Henwood 9.96, with 1 part of the best Newcastle coal.

The difference in the amount of steam capable of being raised by coal from different localities, together with many other important physical properties upon which the economic value of this fuel depends, induced the Government of the United States to institute a series of practical experiments upon the coal of different districts, with a view to ascertain the relative values of the different varieties, more particularly for generating steam and forging iron.

The entire investigation was entrusted to Professor W. R. Johnson, and the results were published in a Report to Congress in the year 1844. The importance of such an investigation in connection with the wants of the steam navy and various branches of national industry, led to a similar undertaking by the Government of Great Britain, which was superintended generally by Sir Henry de la Beche and Dr. Lyon Playfair, whose several Reports to Government were concluded in 1851.

The principal points to be looked for in steam fuel are thus stated by the British Commissioners :—

1. The fuel should burn so that steam may be raised in a short period, if this be desired; in other words, it should be able to produce a quick action.

2. It should possess high evaporative power, that is, be capable of converting much water into steam, with a small consumption of coal.

3. It should not be bituminous, lest so much smoke be generated as to betray the position of ships of war when it is desirable that this should be concealed.

4. It should possess considerable cohesion of its particles, so that it may not be broken into too small fragments by the constant attrition which it may experience in the vessel.

5. It should combine a considerable density with such mechanical structure that it may be easily stowed away in small space; a condition which, in coals of equal evaporative values, often involves a difference of more than 20 per cent.

6. It should be free from any considerable quantity of sulphur, and should not progressively decay, both of which circumstances render it liable to spontaneous combustion.

The results of these very extensive series of experiments are contained in the following Tables:

GENERAL SYNOPTICAL TABLE OF THE CHARACTER AND

	Designation of Coal.	Specific gravity.	Weight per cubic foot, calculated from specific gravity.	Weight per cubic foot, by experiment.	Ratio of actual to calculated weight.	Cubic feet of space required to stow a ton.	Volatile combustible matter, in 100 parts.	Fixed carbon, in 100 parts.
Anthracite.	Beaver Meadow, slope No. 3.....Pa.	1.610	100.645	54.93	0.546	40.78	2.38	88.94
	Beaver Meadow, slope No. 5.....Pa.	1.551	96.93	56.19	0.580	39.86	2.66	91.47
	Forest Improvement .....Pa.	1.477	92.31	53.66	0.581	41.75	3.07	90.75
	Peach Mountain.....Pa.	1.464	91.51	53.79	0.588	41.64	2.96	89.02
	Lehigh .....Pa.	1.590	99.39	55.32	0.557	40.50	5.28	89.15
	Lackawanna .....Pa.	1.421	88.84	48.89	0.550	45.82	3.91	87.74
	Lyken's Valley .....Pa.	1.389	86.82	48.56	0.559	46 13	6.88	83.84
	Beaver Meadow (navy yard) .....Pa.	—	—	55.08	—	40.65	—	—
	Natural coke of Virginia .....Va.	1.323	82.70	46.64	0.564	48.03	12.44	75.08
	Coke of Midlothian coal.....Va.	—	—	32.70	—	68.50	—	—
	Coke of Neff's (Cumberland) coal...Va.	—	—	31.57	—	70.95	—	—
	Mixture, one-fifth Midlothian and four-fifths Beaver Meadow	—	—	54.29	—	41.26	—	—
	Mixture, one-fifth Cumberland and four-fifths Beaver Meadow	—	—	54.51	—	41.09	—	—
Free burning bituminous.	New York and Maryland Mining Company's .....Md.	1.431	89.44	53.70	0.600	41.71	12.31	73.50
	Neff's Cumberland .....Md.	1.337	83.28	54.29	0.652	41.26	12.67	74.53
	Easby's "Coal-in-Store" .....Md.	1.307	81.69	53.47	0.655	41.90	14.98	76.26
	Atkinson and Templeman's .....Md.	1.313	82.09	52.92	0.645	42.33	15.53	76.69
	Easby and Smith's .....Md.	1.332	83.26	51.16	0.614	43.78	15.52	74.29
	Cumberland (navy yard) .....Md.	1.414	88.40	53.29	0.603	42.04	14.87	70.85
	Dauphin and Susquehanna.....Pa.	1.443	90.19	50.54	0.560	44.32	13.82	74.24
	Blossburg .....Pa.	1.324	82.73	53.05	0.641	42.22	14.78	73.11
	Lycoming Creek.....Pa.	1.388	86.74	55.38	0.638	40.45	13.84	71.53
	Quin's Run .....Pa.	1.331	83.22	50.34	0.605	44.50	17.97	72.79
	Karthaus .....Pa.	1.284	80.22	52.54	0.655	42.63	19.53	73.77
	Cambria County.....Pa.	1.407	87.84	53.46	0.608	41.90	20.52	69.37
Bituminous coking.	Barr's Deep Run .....Va.	1.382	86.41	53.17	0.615	42.13	19.78	67.96
	Crouch and Snead's .....Va.	1.451	90.71	53.59	0 591	41.80	24.38	59.98
	Midlothian (900 feet shaft) .....Va.	1.437	87.50	50.52	0.577	44.34	27.28	61.08
	Creek Company's coal .....Va.	1.319	82.48	46.50	0.564	48.17	32.47	60.30
	Clover Hill .....Va.	1.285	80.36	45.40	0.566	49.25	32.21	56.83
	Chesterfield Mining Company's.....Va.	1.289	80.57	45.55	0.565	49.18	32.63	58.79
	Midlothian (average).....Va.	1.294	80.90	54.04	0.568	41.45	29.86	53.01
	Tippecanoe.....Va.	1.346	84.14	45.10	0.536	49.67	34.54	54.62
	Midlothian (" new shaft") .....Va.	1.325	82.82	47.90	0.581	46.76	35.77	56.40
	Midlothian (screened) .....Va.	1.283	80.21	45.72	0.570	48.99	34.70	54 06
	Midlothian (navy yard)..... .....Va.	1.390	86.86	54.47	0.627	41.13	29.12	56.11
Bituminous.	Pictou (from New York).....N. S.	1.318	82.35	53.55	0.650	41.88	27.83	56.98
	Sidney.....N. S.	1.338	83.66	47.44	0.567	47.22	23.81	67.57
	Pictou (Cunard's) .....N. S.	1.325	82.83	49.25	0.595	45.48	25.97	60.74
	Liverpool.....Eng.	1.262	78.89	47 88	0.607	46.78	39.96	54.90
	Newcastle .....Eng.	1.257	78.54	50.82	0.647	44.08	35.83	57.00
	Scotch .....Scotland	1.519	94.95	51.09	0.538	43.84	39.19	48.81
	Pittsburg .....Pa.	1.252	78.37	46.81	0.598	47.85	36.76	54.93
	Cannelton.....Ind.	1.273	79.54	47.05	0.599	47.01	33.99	58.44
	Dry pine wood.....	—	—	21.01	—	106.62	—	—

EFFICIENCY OF THE AMERICAN COALS.

Earthy matter, in 100 parts.	Ratio of fixed to volatile combustible matter.	Total weight of coal consumed.	Pounds burned on a square foot of grate per hour.	Hours required to bring the boiler to steady action.	Cubic feet of water evaporated per hour during steady action.	Pounds of steam to 1 lb. of coal from initial temperature.	Pounds of steam to 1 lb. of coal from 212°.	Pounds of steam furnished by 1 cubic foot of coal.	Total waste in the state of ashes and clinker from 100 of coal.	Weight of clinker alone from 100 of coal.	Average weight, in lbs., of unburnt coke left on the grate after each experiment.	Parts of lead reduced from litharge by 1 of combustible matter of the coal.	Steam from 212° from 1 of combustible matter.
7.11	37.31	3944.5	6.69	3.87	12.57	8.20	9.21	505.5	11.96	1.01	112.4	32.41	10.462
5.15	25.36	4250.5	6.27	2.42	10.66	8.76	9.88	556.1	6.74	0.60	61.2	33.29	10.592
4.41	29.75	3810.0	6.52	3.32	12.89	8.92	10.06	440.8	6.97	0.81	40.2	33.39	10.807
6.13	30.09	7371.9	6.69	3.54	14.04	8.96	10.11	545.7	6.97	3.03	26.6	33.49	10.871
5.56	16.67	3838.2	6.95	3.27	11.63	7.73	8.93	494.0	7.22	1.08	36.1	28.92	9.626
6.85	23.13	4112.5	6.45	2.67	11.92	8.56	9.79	477.7	8.93	1.24	57.2	33.53	10.764
9.25	12.84	2471.0	6.92	2.63	12.89	8.43	9.46	459.6	12.24	4.40	18.0	32.60	10.788
8.10	—	1897.3	4.63	5.08	9.42	7.86	9.08	500.0	8.10	1.40	107.1	—	9.881
11.83	6.27	4209.0	8.15	1.74	12.56	7.47	8.47	395.3	18.46	5.31	60.9	32.49	10.389
16.55	—	1037.0	9.64	2.00	16.50	7.40	8.68	282.6	16.54	10.51	53.2	—	10.343
13.34	—	994.2	8.43	1.17	14.91	7.85	9.00	284.0	13.34	3.55	43.7	—	10.381
8.88	—	2050.0	5.83	3.21	10.06	7.69	8.86	481.1	8.88	4.91	9.5	—	9.725
8.18	—	2074.0	7.97	2.25	12.81	7.97	9.18	498.5	8.18	3.09	16.0	—	9.997
12.40	5.97	2127.7	6.28	1.33	12.79	8.65	9.78	524.8	12.71	5.43	10.1	30.33	11.208
10.34	5.88	4318.4	7.86	1.68	14.80	8.19	9.41	512.7	10.96	4.53	6.1	30.72	10.604
8.08	5.09	1158 0	6.04	1.75	12.73	8.88	10.02	535.6	8.38	1.33	18.2	32.69	10.935
7.33	4.94	2318.2	7.33	0.99	15.70	9.47	10.70	566.2	7.96	2.12	5.1	30.06	11.624
9.30	4.79	4474.5	8.02	1.52	14.97	8.69	9.96	511.1	9.69	3.04	5.3	33.01	11.034
14.98	5.00	—	—	—	—	—	—	—	14.53	2.2:	13.5	27.98	—
11.49	5.37	2557.0	6.86	0.83	13.35	8.31	9.34	472.8	16.36	3.50	23.7	31.18	11.171
10.77	4.95	4295.0	7.77	0.84	15.67	8.64	9.72	515.9	11.20	3.40	13.7	32.54	10.956
13.96	5.18	3073.2	6.33	1.72	12.13	7.92	8.91	493.3	16.92	3.26	46.2	32.89	10.724
8.41	4.05	1883.2	7.29	0.75	13.90	9.08	10.27	517.0	8.94	1.31	14.7	30.90	11.275
7.00	4.11	3643.8	6.66	1.87	12.48	7.92	9.09	477.4	7.89	3.66	52.5	33.31	9.887
9.15	3.66	3488.5	6.68	2.00	12.47	8.04	9.24	486.9	9.75	3.48	14.8	31.46	10.239
10.47	3.43	5072.7	7.60	1.52	13.42	7.84	9.02	478.7	11.07	4.78	6.4	28.01	10.142
14.28	2.50	3834.7	7.13	1.16	11.65	7.30	8.34	445.0	14.34	5.37	6.0	25.77	9.740
10.47	2.24	3417.5	8.68	1.38	14.51	7.50	8.58	403.7	10.70	6.47	5.9	26.99	9.611
8.57	2.03	3769.6	8.59	1.17	14.88	7.44	8.42	391.8	8.64	4.41	10.5	30.52	9.211
10.13	1.79	3775.1	5.84	1.93	8.85	6.71	7.67	347.4	10.60	3.86	11.5	28.53	8.588
8.63	1.92	3876.0	8.46	1.17	14.47	7.95	9.00	410.9	9.07	4.19	10.5	27.38	9.896
14.74	1.78	4506.4	6.68	1.52	10.08	7.30	8.29	448.5	14.83	8.82	6.4	29,03	9.741
9.37	1.60	4904.7	7.37	1.33	10.62	6.74	7.75	350.2	9.72	4.03	11.2	29.17	8.583
9.44	1.68	2918.5	7.60	0.91	13.46	7.66	8.76	418.6	10.26	4.21	17.1	26.80	9.751
9.66	1.57	4132.0	6.24	1.29	10.11	7.84	8.94	408.7	10.27	3.33	14.8	29.74	9.970
14.14	1.95	1463.5	—	—	—	—	—	—	—	4.42	43.2	28.23	—
13.39	2.11	4153.9	7.84	0.94	12.79	7.48	8.41	450.6	13.37	6.13	5.7	28.18	9.710
5.49	2.84	1601.1	8.31	1.18	13.85	7.01	7.99	378.9	6.01	2.24	5.9	29.15	8.497
12.51	2.59	1962.5	9.84	0.85	16.47	7.45	8.48	417.9	12.06	6.19	3.7	26.69	9.648
4.62	1.51	3786.0	8.59	0.86	13.43	6.95	7.48	375.4	5.04	1.86	11.1	27.88	8.255
5.40	1.60	4023.0	8.03	0.84	13.75	7.68	8.66	439.6	5.68	3.14	10.7	27.55	9.178
9.34	1.26	3860.0	10.74	0.96	14.32	6.14	6.95	353.8	10.10	5.63	5.7	27.00	7.719
7.07	2.01	208 4	—	—	10.56	7.03	8.20	384.1	8.25	0.94	9.9	28.89	8.942
4.97	1.72	2465.5	11.09	0.50	15.05	6.31	7.34	348.8	5.12	1.64	6.4	26.53	7.784
0.307	—	2360.5	15.87	—	13.86	4.06	4.69	98.6	0.307	0.00	0.0	—	4.707

ADMIRALTY INVESTIGATION.

ECONOMIC VALUES OF THE WELSH COALS.

Names of Coals employed in the Experiments.	Economic evaporating power, or pounds of water evaporated from 212° by 1 lb. of Coal.	Weight of 1 cubic foot of the Coal as used for Fuel.	Weight of 1 cubic foot as calculated from the density.	Ratio of B. to C. or of the economical to the theoretical weight.	Difference per cent between theoretical and economical weight.	Space occupied by 1 ton in cubic feet (economic weight.)	Results of experiments on cohesive power of Coals (percentage of large Coals).	Evaporating power of Coal, after deducting for combustible matter in residue.	Weight of water evaporated from 212° by 1 cubic foot of Coal.	Rate of evaporation, or number of pounds of water evaporated per hour.
	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I. lbs.	K. Mean.
Aberaman Merthyr ...	10.75	48.9	81.91	.597	67.50	45.80	—	—	525.67	—
Ebbw Vale	10.21	53.3	78.81	.676	45.98	42.26	45.0	10.64	544.19	460.22
Thomas's Merthyr ...	10.16	53.0	82.29	.644	55.26	42.26	57.5	10.72	538.48	520.8
Duffryn.....	10.14	53.22	82.72	.643	55.43	42.09	56.2	11.80	540.12	409.32
Nixon's Merthyr	9.96	51.7	82.29	.628	59.16	43.32	64.5	10.70	614.93	511.4
Binea	9.94	57.08	81.357	.702	42.53	39.24	51.2	10.3	587.92	486.95
Bedwas.....	9.79	50.5	82.6	.611	63.565	44.32	54.0	9.99	494.39	476.96
Hill's Plymouth Work	9.75	51.2	84.78	.603	65.68	43.74	64.0	10.18	499.20	531.6
Aberdare Company's Merthyr	9.73	49.3	81.73	.603	65.78	45.48	74.5	10.27	479.68	489.5
Gadly Nine-feet Seam	9.56	54.8	83.16	.658	51.75	40.87	76.0	10.46	523.88	517.3
Resolven	9.53	58.66	82.354	.712	40.39	38.19	35.0	10.44	559.02	390.25
Mynydd Newydd	9.52	56.33	81.73	.689	45.09	39.76	53.7	10.59	536.26	470.69
Abercarn	9.47	50.3	83.22	.604	65.44	44.53	54.5	9.63	443.96	480.00
Anthracite, Jones & Co.	9.46	58.25	85.786	.679	47.26	38.45	68.5	9.7	565.02	409.37
Ward's Fiery Vein ...	9.40	57.483	83.85	.685	46.00	39.00	46.5	10.6	608.78	529.90
Neath Abbey	9.38	59.3	83.57	.709	49.92	37.77	50.0	9.65	556.23	546.1
Graigola	9.35	60.166	81.107	.742	34.8	37.23	49.3	9.66	581.20	441.48
Gadly Four-feet Seam	9.29	51.6	82.79	.623	60.44	43.41	68.5	10.73	479.36	400.0
Machen Rock Vein ...	9.28	48.1	80.91	.594	68.21	46.56	52.5	9.43	443.96	488.75
Birch Grove, Graigola	9.22	51.0	84.85	.601	66.37	43.92	59.0	9.64	470.22	507.50
Llynvi	9.19	58.3	80.35	.663	50.56	42.02	—	9.58	429.82	399.50
Cadoxton	8.97	58.1	85.97	.675	47.96	38.55	—	9.07	521.15	344.16
Oldcastle Fiery Vein...	8.94	50.916	80.42	.633	57.946	43.99	57.7	—	455.18	464.30
Vivian and Sons'	8.92	47.9	81.04	.591	69.18	46.76	54.0	9.11	427.26	421.25
Llangennech.....	8.86	56.93	81.85	.695	43.76	39.34	53.5	9.2	523.75	373 22
Three-qurtr. Rock Vein	8.84	56.388	83.60	.674	48.26	39.72	52.7	—	498.46	486.86
Pentrepoth	8.72	57.72	81.73	.705	40.17	38.80	46.5	8.98	518.32	381.50
Cwm Frood Rock Vein	8.70	55.277	78.299	.706	41.648	40.52	72.5	9.38	480.90	379.80
Cwm Nanty Gros.....	8.42	56.0	79.859	.701	42.60	40.00	55.7	8.82	471.52	404.16
Brymbo Main	8.36	47.0	81.10	.579	72.55	47.65	—	8.56	392.92	435.83
Vivian and Sons' Rock Vawr	8.08	48.9	81 16	.602	65.97	45.80	70.5	8.19	395.11	492.50
Coleshill	8.0	53.0	80.483	.658	51.85	42.26	62.0	8.34	424.0	406.41
Brymbo Two-yard ...	7.85	47.9	80.04	.598	67.11	46.76	79.5	7.91	376.00	441.66
Rock Vawr	7.68	55.0	80.21	.685	45.83	40.72	65.5	7.88	422.40	397.5
Porth-mawr	7.53	53.3	86.722	.614	62.7	42.02	62.0	7.75	401.34	347.44
Pontypool.....	7.47	55.7	83.35	.676	47.845	40.216	57.5	8.04	416.07	250.40
Pentrefelin	6.36	66.166	84.726	.781	28.051	33.85	52.7	7.4	489.62	247.24

ECONOMIC VALUES OF THE NEWCASTLE COALS.

Names of Coals employed in Experiments.	Economic evaporating power, or number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 cubic foot of the Coal as used for Fuel.	Weight of 1 cubic foot as calculated from the Density.	Ratio of B. to C., or of the economical to the theoretical Weight.	Difference per cent between theoretical and economical Weights.	Space occupied by 1 ton in cubic feet (economic Weight).	Results of experiments on cohesive power of Coal (percentage of large Coals).	Evaporating power of the Coal after deducting for combustible matter in residue.	Weight of water evaporated from 212° by 1 cubic foot of Coal.	Rate of evaporation, or number of lbs. of Water evaporated per hour.
	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I.	K. Mean.
Willington	9.95	53.2	79.87	.666	50.13	42.10	43.00	10.16	529.34	—
Andrews House Tanfield	9.39	52.1	78.86	.660	51.36	42.99	—	9.80	489.21	351.2
Bowden Close	9.38	50.6	79.87	.633	57.84	44.26	38.5	9.67	474.62	—
Haswell Wallsend	8.87	47.4	80.23	.590	69.26	47.25	73.0	9.07	420.43	411.66
Newcastle Hartley	8.23	50.5	80.27	.629	58.95	44.35	78.5	8.65	415.61	308.0
Hedley's Hartley	8.16	52.0	81.79	.635	57.28	43.07	85.5	8.71	424.32	300.8
Bates' West Hartley	8.04	50.8	78.17	.649	53.89	44.13	69.5	8.26	408.43	406.8
West Hartley Main	7.87	48.9	78.86	.620	61.26	45.80	79.0	8.05	384.84	457.50
Buddle's West Hartley	7.82	50.6	77.11	.656	52.39	44.09	80.0	8.01	395.69	413.3
Hastings' Hartley	7.77	48.5	78.04	.621	60.90	46.18	75.5	7.96	376.84	404.5
Carr's Hartley	7.71	47.8	78.23	.611	63.66	46.86	77.5	8.13	368.53	344.3
Davison's West Hartley	7.61	47.7	78.36	.608	64.27	46.96	76.5	7.83	362.99	402.9
North Percy Hartley	7.57	49.1	78.29	.627	59.45	45.62	60.0	7.72	371.68	423.5
Haswell Coal Co.'s Steamboat Wallsend	7.48	49.5	79.36	.623	60.32	45.25	79.5	7.85	370.66	291.8
Derwentwater Hartley	7.42	50.4	78.79	.639	56.32	44.44	63.5	7.66	373.96	451.1
Broomhill	7.3	52.5	77.988	.673	48.55	42.67	65.7	7.66	383.25	397.78
Original Hartley	6.82	49.1	77.98	.629	58.81	45.62	80.0	6.98	334.86	428.4
Cowpen and Sidney's Hartley	6.79	47.9	78.67	.608	64.23	46.76	74.0	7.02	325.24	350.4

ECONOMIC VALUES OF CERTAIN DERBYSHIRE COALS.

Names of Coals employed in Experiments.	Economic evaporating power, or number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 cubic foot of the Coal as used for Fuel.	Weight of 1 cubic foot as calculated from the Density.	Ratio of B. to C., or of the economical to the theoretical Weight.	Difference per cent between theoretical and economical Weights.	Space occupied by 1 ton in cubic feet (economic Weight).	Results of experiments on cohesive power of Coals (percentage of large Coals).	Evaporating power of the Coal after deducting for combustible matter in residue.	Weight of water evaporated from 212° by 1 cubic foot of Coal.	Rate of evaporation, or number of lbs. of Water evaporated per hour.
	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I.	K. Mean.
Earl Fitzwilliam's Elsecar	8.52	47.2	80.85	.583	70.29	47.45	77.0	8.78	402.14	412.70
Hoyland and Co's Elsecar	8.07	48.2	82.16	.586	70.45	46.47	82.5	8.43	388.97	372.91
Earl Fitzwilliam's Park Gate	7.92	47.0	81.79	.574	74.02	47.65	78.0	8·24	372.24	393.75
Butterly Co.'s Portland	7.92	47.1	81.16	.580	72.31	47.55	89.0	8.04	373.03	487.06
Butterly Co.'s Langley	7.80	47.8	78.86	.606	64.97	46.96	84.5	7.98	372.84	398.69
Stavely	7.26	49.9	79.79	.625	59.90	44.88	88.5	7.40	362.27	466.2
Loscoe Soft	6.88	44.8	80.17	.558	78.95	50.00	62.0	6.99	308.22	499.06
Loscoe Hard	6.32	45.9	79.60	.576	73.42	48.80	86.0	...	290.08	431.42

ECONOMIC VALUES OF THE LANCASHIRE COALS.

Names of coals employed in the Experiments.	Economic evaporating power, or number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 cubic foot of the Coal as used for Fuel.	Weight of 1 cubic foot of Coal as calculated from the Density.	Ratio of B. to C., or of the economical to the theoretical Weight.	Difference per cent between theoretical and economical Weight.	Space occupied by 1 ton in cubic feet (economic Weight).	Results of experiments on cohesive power of Coals (per-centage of large Coals).	Evaporating power of the Coal after deducting for combustible matter in the residue.	Weight of Water evaporated from 212° by 1 cubic foot of coal.	Rate of evaporation, or number of lbs. of Water evaporated per hour.
	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I.	K. Mean.
Ince Hall Co.'s Arley	9.47	47.6	79.36	.599	66.72	47.05	73.5	9.35	435.06	487.29
Haydock Little Delf...	9.13	44.9	78.42	.572	74.65	49.88	66.5	9.26	409.93	532.91
Balcarres Arley	8.83	50.5	78.17	.646	54.79	44.35	76.0	9.09	445.91	454.1
Blackley Hurst	8.81	48.0	78.90	.608	64.87	46.66	65.0	9.00	422.88	500.8
Ince Hall Pemberton Yard	8.78	48.0	84.10	.570	75.20	46.66	75.5	—	421.44	461.25
Haydock Rushy Park	8.74	49.3	82.54	.597	67.42	45.43	77.0	8.91	430.88	461.66
Moss Hall Pemberton Four-Feet	8.52	47.3	78.48	.602	65.91	47.35	71.5	8.65	402.99	480.00
Haydock Higher Florida	8.39	49.5	75.99	.651	53.51	45.25	74.0	8.49	415.30	467.50
Ince Hall Pemberton Four-Feet.....	8.34	51.8	79.60	.650	53.66	43.24	74.5	8.45	432.01	497.39
Blackbrook Little Delf	8.29	51.0	78.16	.652	53.25	43.92	61.5	8.55	422.79	440.4
King	8.17	50.8	81.10	.626	59.64	44.09	78.5	8.35	415.03	395.41
Rushy Park Mine.....	8.08	47.0	80.04	.587	70.31	47.65	67.0	8.35	379.76	419.1
Blackbrook Rushy Park	8.02	55.3	80.15	.689	44.93	40.50	80.5	8.26	443.50	481.2
Johnson and Wirthington's Rushy Park...	8.01	50.0	80.10	.624	60.20	44.80	69.0	8.16	400.50	454.5
Laffak Rushy Park ...	7.98	52.6	84.07	.625	59.82	42 58	75.5	8.16	419.74	435.0
Balcarres Haigh Yard	7.90	50.8	80.10	.634	57.67	44.13	80.0	8.23	401.32	398.3
Haydock Florida Main	7.83	48.0	79.04	.507	64.66	46.66	81.5	7.97	375.84	422.50
Wigan Four-Feet.....	7.77	53.4	75.49	.707	41.36	41.94	75.0	8.05	414.91	414.79
Ince Hall Pemberton Five-Feet.....	7.72	51.8	79.17	.654	52.83	43.24	71.5	7.95	399.89	495.20
Cannel (Wigan)	7.70	48.3	76.80	.628	59.00	46.37	95.0	8.06	371.91	381.1
Ince Hall Co.'s Furnace Vein.....	7.47	49.3	81.98	.601	66.28	45.43	71.5	7.84	368.27	435.21
Balcarres Lindsay.....	7.44	51.1	78.61	.650	53.83	43.83	70.0	7.58	380.18	431.5
Caldwell and Thompson's Rushy Park...	7.34	47.5	79.29	.599	56.92	47.15	76.0	7.43	348.65	449.79
Balcarres Five-Feet ...	7.21	49.0	79.11	.619	61.44	45.71	44.5	7.35	353.29	489.5
Moss Hall Pemberton Five-Feet.....	7.13	48.3	80.04	.608	65.71	46.37	78.5	7.29	344.37	417.18
Moss Hall Co.'s New Mine	7.04	48.4	79.73	.607	64.73	46.28	76.5	7.16	340.73	422.08
Caldwell and Thompson's Higher Delf...	6.85	48.4	79.48	.608	64.21	46.28	77.0	6.94	331.54	484.28
Johnson and Wirthington's Sir John	6.32	51.6	81.73	.631	58.39	43.41	82.0	6.62	326.11	362.7

ECONOMIC VALUES OF VARIOUS COALS.

	Names of Coals employed in the Experiments.	Economic evaporating power, or number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 cubic foot of the Coal as used for Fue.	Weight of 1 cubic foot of Coal as calculated from the Density.	Ratio of B to C, or of the economical to the theoretical Weight.	Difference per cent between theoretical and economical Weight.	Space occupied by 1 ton in cubic feet (economic Weight).	Results of experiments on cohesive power of Coals (percentage of large Coals).	Evaporating power of the Coal after deducting for the combustible matter in the residue.	Weight of Water evaporated from 212° by 1 cubic foot of Coal.	Rate of evaporation, or number of lbs. of Water evaporated per hour.
		A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I.	K. Mean.
Scotch Coals.	Wallsend Elgin	8.46	54.6	78.611	.694	43.78	41.02	64.0	8.67	460.82	435.77
	Wellewood	8.24	52.6	79.78	.659	53.57	42.58	80.0	8 39	433.42	438.5
	Dalkeith Coronation Seam	7.71	51.66	78.611	.657	52.17	43.36	88.2	7.86	398.29	370.06
	Kilmarnock Skerrington	7.66	44.7	77.42	.577	73.19	50.11	63.5	7.82	342.40	470.83
	Fordel Splint	7.56	55.0	78.611	.699	42.92	40.72	63.0	7.69	415.80	464.95
	Grangemouth	7.40	54.25	80.48	.674	48.35	40.13	69.7	7.91	401.45	380.4
	Eglinton	7.37	52.0	79.84	.651	51.48	43.07	79.5	7.48	383.24	406.2
	Dalkeith Jewel Seam	7.08	49.8	79.672	.625	59.984	44.98	85.7	7.10	352.58	355.18
Slievardagh Irish Anthracite		9.85	62.8	99.57	.630	58.55	35.66	74.0	10.49	618.58	473.18
Various	Coleshill Co.'s Bagilt Main	8.33	49.6	79.17	.626	59.61	45.16	79.0	8.50	413.16	461.25
	Ewloe	7.02	50.4	79.54	.633	57.81	44.44	84.0	7.16	353.80	363.95
	Ibstock	6.91	47.3	80.54	.587	70.27	47.35	62.0	7.02	326.84	454.16
Lydney (Forest of Dean)		8.52	54.44	80.046	.68	47.02	41.14	55.0	8.98	463.86	487.19
Conception Bay, Chili		5.72	—	80.54	—	—	—	—	5.96	—	425.0
Patent Coals.	Warlich's Patent Fuel	10.36	69.05	72.248	.955	4.49	32.44	—	10.60	715.35	457.84
	Livingstone's Steam Fuel	10.03	65.6	73.86	.888	12.59	34.14	—	10.57	657.96	483.95
	Lyon's Patent Fuel	9.58	61.1	74.73	.817	22.30	36.66	—	9.77	585.33	409.1
	Wylam's	8.92	65.08	68.629	.948	5.45	34.41	—	9.74	580.51	418.89
	Bell's	8.53	65.3	71.124	.918	8.91	34.30	—	8.65	557.0	549.11
	Holland and Green's	7.59	64.8	81.23	.797	25.35	34.56	—	7.86	491.83	470.0

AVERAGE VALUE OF COALS FROM DIFFERENT LOCALITIES.

Locality.	Evaporating power, or number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Rate of evaporation, or number of lbs. evaporated per hour.	Weight in lbs. of 1 cubic foot of Coal as used for Fuel.	Space occupied by 1 ton in cubic feet.	Results obtained in experiments on cohesive power of Coals (percentage of 1 rge Coals).	Percentage amount of Sulphur contained in Coals.
	A.	B.	C.	D.	E.	F.
Average of 37 samples from Wales.....	9.05	448.2	53.1	42.71	60.9	1.42
„ 17 „ Newcastle.	8.37	411.1	49.8	45.3	67.5	0.94
„ 28 „ Lancashire	7.94	447.6	49.7	45.15	73.5	1.42
„ 8 „ Scotland...	7.70	431.4	50.0	49.99	73.4	1.45
„ 8 „ Derbyshire	7.58	432.7	47.2	47.45	80.9	1.01

The evaporating vessels employed in the American and British researches were of different construction. In the former a cylindrical boiler, 30 feet in length by 3½ in diameter, was set over a furnace, and the heated gases, after passing through two interior return flues, each 1 foot in diameter, escaped by side flues exterior to the boiler to the chimney, making the entire length of circuit for the products of combustion 121 feet. The grate surface was 16¼ square feet, and the area of heat-absorbing surface 377½ square feet, so that the ratio of grate surface to absorbing surface was as 1 to 23⅓. The chimney was 63 feet high, with a cross section of 324 square inches.

In the experiments of the British Commission a Cornish boiler was used, 12 feet long and 4 feet external diameter, with an interior flue 2 feet in diameter, within which the furnace was built. The heated gases from the furnace, after traversing the central flue, returned to the front by two side flues external to the boiler, and escaped by a common flue passing under the bottom of the boiler to the chimney, making a circuit of altogether 36 feet in length. The surface of grate was 5 square feet, and the heat-absorbing surface was 197.6 square feet, and the ratio of grate surface to absorbing surface consequently as 1 to 39½; the chimney was 35½ feet high, and had a cross section of 182¼ square inches. The amount of coal burned during the whole series of 144 trials at Washington was 62½ tons; that consumed in the 82 trials at London was 14½ tons; the average weight of coal burnt at one trial in the former case being 978 lbs., and in the latter 391½ lbs.

In the Table of American results the bulk occupied by a cubic foot of coal is estimated upon the coal in the condition in which it is sent into the market, large and small together. The corresponding column in the series of British experiments has reference to the coal broken into pieces, none of which exceeded a pound in weight. A greater uniformity of result is certainly to be expected from the latter mode of proceeding, and the amount of steam raised by equal bulks of coal measured in these two methods will be in favour of the latter.

In comparing, therefore, the relative values of the coal by measure, which is of importance for ships' use, the mode of measurement or the size of the pieces must be taken into account, and if those coals in the two series of experiments be compared whose specific gravities are identical, it will be found that on an average a cubic foot in the marketable state will weigh about 10 per cent less than a cubic foot broken into pieces, none of which exceed 1 lb. in weight. The amount of steam raised per cubic foot of coal will therefore require to be increased 10 per cent in the American experiments to make the results strictly comparable with those of the British researches.

In the British experiments the amount of moisture contained in the coal was not deducted in calculating the evaporative value, as it was considered more practical to test their values in the condition in which they were sent to market. The boiler employed by the British Commissioners was, from its small size, not calculated to exhibit the maximum effect obtainable from the fuel, being 20 per cent less efficient than the boilers employed at the Cornish mines; but as all the varieties of coal were submitted to the same treatment, it was presumed that their relative values would be elicited from a comparison of the results obtained.* Three experiments were made with each fuel. A different amount of air was admitted to the grate in many of the trials, by means of a damper in the chimney, and a mean was taken of the quantity of steam raised in each case, which was supposed to indicate the practical value of the coal; in others the same amount of air was admitted, or the area of the chimney was kept constant in all three trials. It would have been very desirable to have varied the amount of air admitted to the fuel, as well as the mode of its admission, to a greater extent than was done in these experiments, in order to have elicited the greatest

* This is a serious objection to these researches, as different descriptions of coal require very different treatment, and Cornish, different management, to marine boilers.

possible practical efficiency of each variety of coal, and, if possible, to have ascertained the conditions required by specimens of different physical and chemical constitution, in order to develope their full calorific value. In many instances too much, in others too little, air appears to have been admitted, although the fact of no combustible ingredients being found amongst the gases which escaped from the chimney, implies that the carbon had been completely converted into carbonic acid.

The relation between the composition of the coal, as ascertained by analysis, and its value for producing steam, is not by any means very clearly brought out by the experiments, which indeed prove, that the only trustworthy method of determining the value of a fuel, especially for steam purposes, is that of practical use under the boiler, where several tons and not lbs. are consumed.

Another important feature in steam-coal is the character of the ash, which ought to be infusible, so as to fall through the grates as soon as produced. An ash which melts, forming *clinkers* or *scars*, is very objectionable, from the obstruction they offer to the draught, the extra labour and wear and tear of stoking, and the cooling effects of the rush of cold air through the flues while the fireman is clearing his grates. This property is overlooked in these and similar researches, as the combustion is conducted too leisurely, and at a temperature inside the fire-place which does not test this character of the ash. The stoking on board a steamer in a gale of wind had no counterpart in these land experiments, and the highest evaporative power is comparatively worthless if associated with a fusible ash.

Another feature of steam-coal, somewhat more difficult to describe, is the peculiar facility which some of them possess of forming a long flame, which is of more value than mere high evaporative power tested under conditions rarely or never realized in actual practice.

Some are inclined to consider the total amount of carbon as a measure of the practical evaporative power of coal, and amongst these Professor Johnson, who has adduced the following Table in support of this test. The evaporative trials were performed by burning about 2 tons of each kind of coal under a boiler capable of evaporating 15 cubic feet of water per hour.

TABLE I.

Designation of the Coal.	Specific gravity.	Proximate Analysis. Composition of raw Coal in 100 parts. Moisture expelled below 250° F.	Sulphur.	Volatile combustible matter.	Fixed Carbon.	Earthy matter.	Ratio of fixed to 1 of volatile combustible matter.	Ultimate Analysis, calculated for 100 parts of combustible matter. Carbon.	Hydrogen.	Oxygen and Nitrogen.	Calculated evaporative power of the Carbon alone in one of combustible matter, by Dulong's coefficient for water at 212°.	Practical Evaporative Power. Pounds of water from 212° to 1 of combustible matter. Evaporated from the boiler.	Vapourisable by the heat expended on the gaseous products of combustion.	Total of evaporative efficiency of one part of combustible matter by experiment on a practical scale.	Difference between the calculated and the experimental efficiency of the combustible matter.
Summit Postage railroad, Cambria Co. .....Pa.	1.3617	0.700	1.500	18.197	64.245	15.360	3.535	91.955	5.876	2.178	11.522	10.238	1.312	11.550	— .028
Midlothian "new shaft" Vir.	1.3006	0.914	2.282	29.274	62.050	5.480	1.966	93.620	5.739	0.641	11.731	10.191	1.269	11.460	+ .272
Newcastle .....England	1.2567	1.461	—	28.312	68.377	1.850	2.415	84.157	5.626	10.218	10.545	9.178	1.720	10.898	— .353
Clover Hill..... .....Virginia	1.2887	1.277	0.514	28.409	65.425	4.375	2.268	83.393	4.958	11.649	10.445	8.588	1.949	10.537	— .082
Scotch	1.2759	1.365	—	35.586	60.342	2.707	1.696	82.952	5.607	11.441	10.393	8.868	1.338	10.206	+ .187
Careyville, Kentucky, and Cannelton .....Indiana	1.3920	1.150	—	30.669	44.493	23.687	1.450	76.335	6.668	17.002	9.565	7.734	1.823	9.557	+ .008
Averages	—	—	—	—	—	—	—	—	—	—	10.700	9.133	1.6585	10.701	

In calculating the evaporative power the latent heat of steam is taken at 1030°. The waste or residue unburnt and the incombustible matters are deducted, and both the calculated evaporative power of the carbon constituent, and the total evaporation by experiment, are referred to and calculated for, 1 part by weight of combustible matter. 1 part of carbon is assumed with Dulong to be capable in burning of heating 7170 parts of water 1° C., or 12906 parts 1° F.

The correspondence between the 15th and 18th columns appears to demonstrate that the heating power of bituminous coals is practically proportionate to the carbon which they severally contain. On the average, the coals consumed in evaporating water from the boiler 85.35, and on the products of their combustion 14.65 per cent of their heating power.*

The average excess of hydrogen for the six varieties, as deduced from columns 13 and 14, is 4.636 per cent, which, calculated on the assumption that 1 part by weight of hydrogen is capable of raising 62.535 (Dulong) parts of water 1° F., ought to possess an evaporative power of 2.814. This would raise the average in the 15th column from 10.7 to 13.514 as the calculated evaporative power of the unit of combustible matter, showing the calculated to be 26.3 per cent higher than the experimental effect. With our existing arrangements for burning fuel, therefore, either time is not allowed for any of this heat to be made available, or the hydrogen, by passing from the solid state as it exists in the coal, to the gaseous condition as an ingredient of aqueous vapour, and by rendering a large portion of the carbon gaseous in the form of carbo-hydrogen, appears to be rendered valueless as a constituent of coal. Whether this apparent loss is necessarily the case, or whether by employing condensed air to feed the fire, and replace the action of the chimney, as proposed by Mr. Prideaux, together with an improved regulation of the quantity of air and mode of admitting it, much of this heat might not be economised, remains still a problem for solution.

The amount of oxygen consumed by fuel in combustion, or the amount of oxide of lead reduced to the state of metal, has been also assumed to be a measure of its evaporative value. The extent to which this and the two preceding methods of computation are trustworthy, as elicited by the extensive series of experiments of the Admiralty investigation, will be seen by the following Table, in which the actual amounts of steam raised are placed in juxtaposition with the quantities of lead reduced, the total amounts of carbon, and the total quantities of coke left by the coal on charring. An additional column shows the amount of carbon contained in the volatile matters.

* This result is opposed to that found by Mr. L. Thompson, in experiments made on a considerable scale at the Western Gas Works, and for a general discussion of this point, see Dr. Ure's "Dictionary of Manufactures, &c."

TABLE II.

	Names of Coals employed in the Experiments.	lbs. of water evaporated by 1 lb. of coal.	lbs. of lead reduced from litharge by 1 of coal.	Total amount of carbon contained in 100 of coal.	Coke or fixed carbon left by 100 of coal ash deducted.	Carbon contained in volatile matter of coal.
Welsh Coals.	Aberaman Merthyr	10.75	32.0	90.94	83.55	7.39
	Ebbw Vale	10.21	32.0	89.78	76.	13.78
	Thomas's Merthyr	10.16	33.0	90.12	84.85	5.27
	Duffryn	10.14	30.0	88.26	81.04	7.22
	Nixon's Merthyr	9.96	33.2	90.27	77.86	12.41
	Binea	9.94	31.6	88.66	84.14	4.52
	Bedwas	9.79	28.2	80.61	64.76	15.85
	Hill's Plymouth Work	9.75	34.1	88.49	79.86	8.63
	Aberdare Company's Merthyr	9.73	34.1	88.28	82.57	5.71
	Gadly Nine-feet Seam	9.56	34.2	86.18	81.20	4.98
	Resolven	9.53	32.2	79.33	74.49	4.84
	Mynydd Newydd	9.52	30.5	84.71	71.56	13.15
	Abercarn	9.47	31.8	81.26	66.36	14.90
	Anthracite, Jones and Co.	9.46	33.5	91.44	91.38	0.06
	Ward's Fiery Vein	9.40	31.5	87.87	—	—
	Neath Abbey	9.38	31.2	89.04	57.87	31.17
	Graigola	9.35	32.1	84.87	82.26	2.61
	Gadly Four-feet Seam	9.29	34.2	88.56	83.35	5.21
	Machen Rock Vein	9.23	30.7	71.08	61.35	9.73
	Birch Grove, Graigola	9.22	33.3	84.25	80.67	3.58
	Llynvi	9.19	32.2	87.18	69.9	17.28
	Cadoxton	8.97	31.8	87.71	78.43	9.28
	Oldcastle Fiery Vein	8.94	31.4	87.68	77.16	10.52
	Vivian and Sons' Merthyr	8.82	31.0	82.75	61.79	20.96
	Llangennech	8.86	32.7	85.46	77.15	8.31
	Three-quarter Rock Vein	8.84	26.6	75.15	51.54	23.61
	Pentrepoth	8.72	31.2	88.72	79.14	9.58
	Cwm Frood Rock Vein	8.70	28.8	82.25	62.8	19.45
	Cwm Nanty Gros	8.42	29.7	78.36	60.0	18.36
	Brymbo Main	8.36	30.3	77.87	51.18	26.69
	Vivian and Sons' Rock Vawr	8.08	30.0	79.09	54.3	24.79
	Coleshill	8.0	26.1	73.84	47.08	26.76
	Brymbo Two-yard	7.85	29.5	78.13	50.30	27.93
	Rock Vawr	7.68	28.9	77.98	54.95	23.03
	Porth-mawr	7.53	24.8	74.70	48.38	26.32
	Pontypool	7.47	31.5	80.70	59.28	21.42
	Pentrefelin	6.36	30.5	85.52	78.91	6.61
Newcastle Coals.	Willington	9.95	31.3	86.81	71.11	15.7
	Andrews House Tanfield	9.39	31.1	85.58	62.99	22.59
	Bowden Close	9.38	31.9	84.92	67.41	17.51
	Haswell Wallsend	8.87	31.5	83.47	62.50	20.97
	Newcastle Hartley	8.23	31.9	81.81	57.47	24.34
	Hadley's Hartley	8.16	30.4	80.26	63.19	17.07
	Bates' West Hartley	8.04	28.9	80.61	—	—
	West Hartley Main	7.87	30.3	81.85	56.59	25.26
	Buddle's West Hartley	7.82	29.5	80.75	—	—
	Hastings' Hartley	7.77	28.6	82.24	32.66	49.58
	Carr's Hartley	7.71	30.9	79.83	55.42	24.41
	Davison's West Hartley	7.61	30.1	82.26	53.65	28.61
	North Percy Hartley	7.57	29.1	80.03	53.96	26.07
	Haswell Coal Company Steam-boat Wallsend	7.48	31.5	83.71	55.45	26.26
	Derwentwater Hartley	7.42	29.1	87.01	51.1	35.91
	Broomhill	7.3	25.5	81.70	56.13	25.57
	Original Hartley	6.82	26.6	81.18	55.15	26.03
	Cowper and Sidney Hartley	6.79	28.7	82.20	56.23	25.97

	Names of Coals employed in the Experiments.	lbs. of water evaporated by 1 lb. of coal.	lbs. of lead reduced from litharge by 1 of coal.	Total amount of carbon contained in 100 of coal.	Coke or fixed carbon left by 100 of coal, ash deducted.	Carbon contained in volatile matter of coal.
Derbyshire Coals.	Earl Fitzwilliam's Elsecar	8.52	30.1	81.98	59.14	22.77
	Hoyland and Co.'s Elsecar	8.07	29.7	80.05	58.77	21.28
	Earl Fitzwilliam's Park Gate	7.92	30.1	80.07	59.9	21.17
	Butterly's Co.'s Portland	7.92	31.0	80.41	59.67	20.74
	Butterly's Co.'s Langley	7.80	30.0	77.97	50.25	27.72
	Stavely	7.26	28.1	79.85	55.46	24.39
	Loscoe Soft	6.88	28.	77.49	50.5	26.99
	Loscoe Hard	6.32	29.6	—	—	—
Lancashire Coals.	Ince Hall Co.'s Arley	9.47	32.5	82.61	62.47	20.14
	Haydock Little Delf	9.13	29.3	79.71	54.68	25.03
	Balcarres Arley	8.83	29.4	83.54	59.57	23.97
	Blackley Hurst	8.81	29.6	82.01	53.79	28.22
	Ince Hall Pemberton Yard	8.78	30.0	80.78	58.26	22.52
	Haydock Rushy Park	8.74	29.8	77.65	55.72	21.93
	Moss Hall Pemberton Four-feet	8.52	28.5	75.53	49.12	26.41
	Haydock Higher Florida	8.39	29.7	77.33	48.05	29.28
	Ince Hall Pemberton Four-feet	8.34	28.8	77.01	56.01	21.0
	Blackbrook Little Delf	8.29	28.7	82.70	54.17	28.53
	King	8.17	31.3	73.66	53.68	19.98
	Rushy Park Mine	8.08	29.0	77.76	50.97	26.79
	Blackbrook Rushy Park	8.02	30.4	81.16	55.42	25.74
	Johnson and Wirthington's Rushy Park	8.01	28.9	79.50	55.33	24.17
	Laffak Rushy Park	7.98	26.9	80.47	53.44	27.03
	Balcarres Haigh Yard	7.90	28.2	82.26	62.19	20.07
	Haydock Florida Main	7.83	29.3	77.49	52.38	25.11
	Wigan Four-feet	7.77	30.0	78.86	55.77	23.09
	Ince Hall Pemberton Five-feet	7.72	28.7	68.72	42.16	26.56
	Cannel (Wigan)	7.70	29.9	79.23	55.49	23.74
	Ince Hall Co.'s Furnace Vein	7.47	28.6	74.74	54.36	20.38
	Balcarres Lindsay	7.44	26.2	83.90	55.85	28.05
	Caldwell and Thompson's Rushy Park	7.34	29.4	76.17	57.2	18.97
	Balcarres Five-feet	7.21	26.0	74.21	46.69	27.52
	Moss Hall Pemberton Five-feet	7.18	27.5	76.16	50.08	26.08
	Moss Hall Co.'s New Mine	7.04	27.0	77.50	54.54	22.96
	Caldwell and Thompson's Higher Delf	6.85	28.4	75.40	48.25	27.15
	Johnson and Wirthington's Sir John	6.32	23.8	72.86	44.75	28.11
Scotch Coals.	Wallsend Elgin	8.46	29.1	76.09	47.75	28.34
	Wellewood	8.24	28.5	81.36	56.26	25.10
	Dalkeith Coronation Seam	7.71	24.5	76.94	50.4	26.54
	Kilmarnock Skerrington	7.66	30.3	79.82	48.05	31.77
	Fordel Splint	7.56	29.0	79.58	48.03	31.55
	Grangemouth	7.40	28.5	79.85	53.08	26.77
	Eglinton	7.37	24.3	80.08	52.5	27.58
	Dalkeith Jewel Seam	7.08	26.4	74.55	45.43	29.12
	Slievardagh Irish Anthracite	9.35	30.1	80.03	—	—
Various.	Coleshill Co.'s Bagitt Main	8.33	26.1	88.48	54.18	34.3
	Ewloe	7.02	31.1	80.97	50 87	30.1
	Ibstock	6.91	25.1	74.97	44.81	30.16
	Sydney (Forest of Dean)	8.52	26.0	—	—	—
	Conception Bay, Chili	5.72	25.8	—	—	—
Patent Coals.	Warlich's Patent Fuel	10.36	31.5	90.02	—	—
	Livingstone's Steam Fuel	10.03	32.5	86.07	—	—
	Lyon's Patent Fuel	9.58	31.4	86.36	—	—
	Wylam's	8.92	28.8	79.91	60.96	18.95
	Bell's	8.53	28.5	87.88	66.74	21.14
	Holland and Green's	7.59	23.7	70.14	—	—

If the average quantities of steam raised by coals which are capable of reducing the same amount of lead, be now compared, as shown in Table III., it will be observed that although on the

TABLE III.

Lead reduced by 1 part of Coal.	Steam Generated by 1 Part of Coal.									
	Average number of Specimens.	Welsh Coals.	Average number of Specimens.	Newcastle Coals.	Average number of Specimens.	Derbyshire Coals.	Average number of Specimens.	Lancashire Coals.	Average number of Specimens.	Scotch Coals.
Above 34	4	9.58	—	—	—	—	—	—	—	—
33—34	5	9 75	—	—	—	—	—	—	—	—
32—33	6	9.65	—	—	—	—	1	9.47	—	—
31—32	9	9.02	6	8.88	1	7.92	1	8.17	—	—
30—31	5	9.07	4	7.84	3	8.08	3	8.19	1	7.66
29—30	2	8.13	2	7.62	2	7.19	9	8.32	2	8.0
28—29	3	8.72	3	7.80	2	7.07	8	7.88	2	7.82
27—28	—	—	—	—	—	—	2	7.08	—	—
26—27	2	8.42	1	6.82	—	—	3	7.54	1	7.08
25—26	—	—	1	7.3	—	—	—	—	—	—
24—25	1	7.53	—	—	—	—	—	—	2	7.58
23—24	—	—	—	—	—	—	1	6.32	—	—

whole the amount of lead may be taken as an approximative test of the value of fuel, it can by no means be relied on as an exact measure of that value.

The same may be observed with reference to the amount of fixed carbon as shown in Table IV. for differences of 5 per cent.

TABLE IV.

Percentage of Coke.	Steam Generated by 1 Part of Coal.									
	Average number of Specimens.	Welsh Coal.	Average number of Specimens.	Newcastle Coal.	Average number of Specimens.	Derbyshire Coal.	Average number of Specimens.	Lancashire Coal.	Average number of Specimens.	Scotch Coal.
Above 90	—	—	—	—	—	—	—	—	—	—
80—85	9	9.74	—	—	—	—	—	—	—	—
75—80	6	9.43	—	—	—	—	—	—	—	—
70—75	2	9.52	1	9.95	—	—	—	—	—	—
65—70	2	9.34	1	9.38	—	—	—	—	—	—
60—65	5	8.95	3	8.81	—	—	2	8.68	—	—
55—60	2	8.42	7	7.46	—	7.94	10	8.09	1	8.24
50—55	4	8.28	3	7.52	5	7.34	10	7.99	3	7.49
45—50	2	7.71	—	—	2	—	4	7.81	4	7.69
40—45	—	—	—	—	—	—	2	7.02	—	—
30—35	—	—	1	7.77	—	—	—	—	—	—

The total amounts of carbon contained in the different coals classed together for every 5 per cent of difference, and an average taken of the amount of steam raised from these, is shown in Table V., which, although it bears out the general fact of the

TABLE V.

Total Percentage of Carbon.	Steam Generated by 1 Part of Coal.									
	Average number of Specimens.	Welsh Coals.	Average number of Specimens.	Newcastle Coals.	Average number of Specimens.	Derbyshire Coals.	Average number of Specimens.	Lancashire Coals.	Average number of Specimens.	Scotch Coals.
Above 90	3	10.12	—	—	—	—	—	—	—	—
85—90	15	9.57	3	8.92	—	—	—	—	—	—
80—85	6	9.19	14	7.84	4	8.10	9	9.39	2	7.80
75—80	7	8.39	1	7.71	3	7.31	14	7.92	5	7.96
70—75	3	8.25	—	—	—	—	4	7.26	1	7.08

carbon being in proportion to the steam raised, does not warrant the carbon being made an exact measure of the heating power.

This branch of our subject is still in a most unsatisfactory position, and there is no known scientific method by which to estimate the commercial value of a coal.

The following summary of experiments upon the introduction of vapour into the fire, by Dr. Fyfe, are interesting. As the mean of 13 observations, when a well-regulated and properly-divided current of vapour was conducted over the flame, 1 lb. of Scotch coal vapourised 9.49 lbs. of water from 0° C. Another kind of coal gave as the mean of 10 observations, which varied from 9.23 to 13.34, 10.97 lbs. of water from 0° C. A direct comparative trial, made with a steam boiler, showed that 537 lbs. of coal, assisted by the action of vapour, effected as much as 812 lbs. without it, and for this purpose 4 lbs. of the vapour were conducted through the fire for every 100 lbs. that were liberated. If these be deducted, we obtain instead of 10.97, only 10.53 as the actual effect produced, which is still 37 per cent more than was obtained by the unassisted coal.

The Hessian Society for the Promotion of Arts and Manufactures examined experimentally the value of wood, peat, and coal burnt under six different well-arranged coppers, and found

that 1 lb. of cleft beech wood two years felled converted 2.075 lbs. of water from 0° C. into vapour, 1 lb. of peat evaporated 1.991 lb., and 1 lb. of small coal 5.201 lbs. of water.

SECONDARY PRODUCTS OBTAINED FROM FUEL.

In conformity with the arrangement of this work we have now to review the other branches of chemical manufacture in which fuel is either employed as the raw material for the production of other compounds, or the object of which is to convert the waste products from the manufacture of artificial fuel into useful commercial articles.

Taking the various kinds of fuel in the order they have hitherto been handled, and commencing with the products obtained from wood, we have to describe the methods of obtaining *pyroligneous acid* or *wood-vinegar*, with its accompanying *wood-* or *pyroxylic spirit*, and the various compounds with metallic bases which are generally connected with its production.

Pyroligneous Acid—Wood-Vinegar.—Glauber, in his works (*Furnis novis philosophicis*, 1648, and *Mirac. Mundi*, 1658), includes *spiritum acidum* amongst the products of the dry distillation of wood, which is simply common vinegar, and is consequently called *Acetum lignorum*. Boyle likewise mentions *acetum* among the same products in his *Chemista Scepticus* (1661); and Boerhaave *aceta acetosa* in his *Elementis Chemiæ* (1732). There can be therefore no doubt that the existence of an acid liquid amongst the products of the dry distillation of wood was known in the middle of the 17th century, although it is not very certain that the acid was clearly recognised as acetic, because the expression *acetum* was applied at that time as a generic term for acids, and not restricted to vinegar. As late even as the end of the last century, in the times of Lavoisier and Fourcroy, the *acide pyro-ligneux* was considered a distinct acid, until in the year 1800 the latter chemist proved, conjointly with Vauquelin, that the acid of wood was impure acetic acid.

The manufacturing process for obtaining vinegar (acetic acid) from the products of the distillation of wood is the result of the researches of Stolze (given in his work on the Purification and Application of Crude Pyroligneous Acid) and of Mollerat, few modifications of their original process having been introduced in the manufacture.

The general nature of the products resulting from the dry distillation of wood has been already noticed, and it has been shown how one portion of the carbon of the wood remains as a solid residue in the form of charcoal, while the remainder escapes partly in the form of permanent gases, and partly as vapours which condense into liquids at the ordinary atmospheric temperature. Two distinct liquids are constantly obtained, which separate into layers in the receivers. The *tar*, which is the heavier, is of a brownish-black colour, thick, opaque, of a peculiar odour, and composed of a number of substances as yet very imperfectly known. Some of these are volatile, oily bodies (*Empyreumatic oil*, Pyrelain, Pyrostearine), and hold in solution another class of substances which have a strong resemblance to the vegetable resins (*Empyreumatic resin*, Pyrretine). This solution also contains extractive matter, and more or less of the substances named hereafter, particularly acetic acid. The lighter liquid consists of an aqueous solution of numerous substances, some of which are likewise very imperfectly known, as Schweitzer and Weidmann's *Xylite* (Gmelin's Lignon) and *Mesite*; others have been more fully investigated, amongst which are acetic acid, wood-spirit (hydrated oxide of methyl), acetate of methyl, creosote, and acetone.

The acetic acid has a powerful affinity for the resinous constituents of the tar, with which it forms compounds that are not easily decomposed. For this reason the crude aqueous liquid, or raw wood-vinegar, always retains a considerable quantity of resin in solution, which is accompanied by the empyreumatic extractive matters which are themselves soluble in water. These impurities cling pertinaciously to the crude vinegar, and are the cause of its brown colour and peculiar empyreumatic taste. The remarkable preservative and anti-putrescent properties of crude vinegar are also due in some measure to these admixtures, as well as to the presence of creosote, which it often contains to the extent of 1 per cent.

These products are obtained in every process of charring, although their relative quantities are subject to great variation. There is therefore no scientific objection to the two processes of charcoal-burning and vinegar-making being carried on conjointly, if other circumstances did not create practical difficulties in the way of such a combination. In the manufacture of charcoal, the cost of carriage generally obliges the burner to

locate himself where wood is abundant, and change his position when it becomes exhausted, while in doing this he is generally placing himself at a great distance from a market for the volatile products, and in situations where the requisite apparatus and materials for collecting these products are not easily obtained or conveyed. A fixed plant becomes essential where the volatile products are to be thoroughly economised, and this is incompatible with the charring of large quantities of wood at once under a moveable covering, as is practised in the meiler process; and lastly, the quality of the charcoal must suffer if the process is so conducted as to afford the largest possible quantity of tar and pyroligneous acid. Wherever, therefore, the charcoal is the chief object of the manufacture, it is generally carried on without attention being paid to the collecting of tar, and when the vinegar and tar are to be collected, the charcoal becomes a secondary source of profit. The latter process, indeed, is very seldom combined with the manufacture of charcoal for fuel.

It is reasonable to suppose that as wood is an organic structure made up of numerous chemical ingredients, each of these several constituents must exercise a special and unequal amount of influence upon the production of vinegar during the process of distillation; and indeed experiment has proved that the acid is chiefly derived from the woody fibre (cellulose) and the bodies allied to it. Payen is of opinion that it is not so much the cellulose itself, as the encrusting matter of the cells, which is the source of the vinegar; having found that pure cellulose yielded less acid than the entire wood, in which there is abundance of the latter substance. Stolze observed that different species of wood, thoroughly exhausted of the soluble matters and resin, still yielded unequal quantities of vinegar, although, what is remarkable, they afforded very nearly the same total amount of distilled products, namely, about 47 per cent. The less bark there is upon the wood, the greater is the yield of vinegar, and trunk wood consequently produces more acid than brush-wood.

The following results are selected from Stolze's experiments:

Woods.	100 parts of Wood, dried at 99.4° F. gave the following quantities.					
	Charcoal.	Uncondensable Gases.	Tar.	Crude Pyroligneous Acid.	Pure Hydrated Acetic Acid.	Amount of pure Hydrated Acetic Acid in the Crude Pyroligneous Acid per cent.
Birch (*Betula alba*)	24.4	22.0	8.6	45.0	4.47	10.01
Beech (*Fagus sylvatica*)	24.6	21.8	9.5	44.0	4.29	9.83
Oak (*Quercus robur*)	26.2	21.7	9.1	43.0	3.88	9.10
Ash (*Fraxinus excelsior*)	22.1	22.3	8.8	46.8	3.72	8.11
White Poplar (*Populus alba*)	23.4	22.7	8.0	45.8	3.28	7.10
Bird-cherry (*Prunus padus*)	21.6	24.3	10.3	47.3	2.92	6.73
Juniper (*Juniperus communis*)	22.7	20.8	10.7	45.8	2.34	5.28
Spruce-fir (*Pinus abies*)	21.2	23.9	13.7	41.2	2.16	5.28
Scotch-fir (*Pinus sylvestris*)	21.5	24.3	11.8	42.4	2.14	5.10

The hard woods, according to these results, afford much more acetic acid than the soft and coniferous woods, the produce averaging from 2.14 to 4.47 per cent of hydrated acetic acid, which is equivalent to from 1.8 to 3.8 per cent of anhydrous acid. It is probable that the mode of conducting the distillation has still more influence upon the quality and quantity of the produce than the nature of the wood, but unfortunately no experiments have been made upon this subject.

According to Karsten (compare p. 59) a quick process of distillation yields on an average 25.6 per cent, while a slow process at a low temperature only affords 14.3 per cent of volatile products. It is also well known that the tar which comes over in the commencement of an operation is always limpid, but increases in consistence as the process advances, and at last becomes nearly solid. It still remains to be shown at what period of the distillation, and by what method of conducting it, the largest produce of acetic acid may be secured.

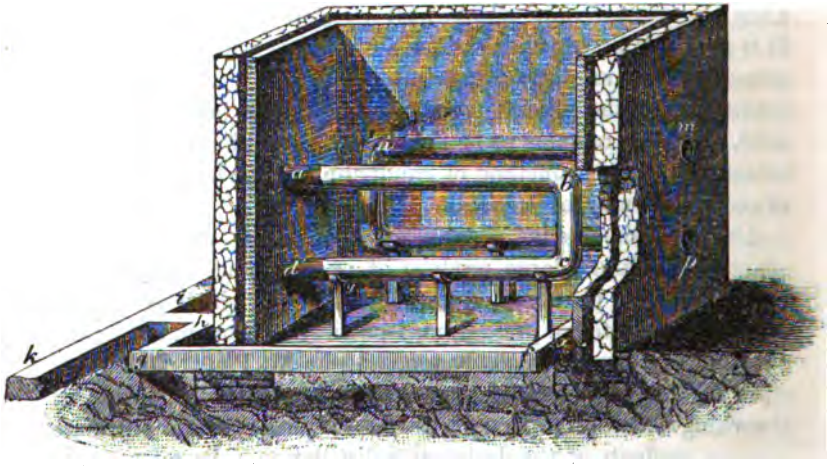
Althongh the meiler process for carbonizing wood is little adapted to afford a large produce of pyroligneous acid, yet the little which is produced, the collection of which is seldom or never attempted at present, may possibly be economized by the adoption of a process recently proposed by M. Paur. The principle of this plan consists in exposing a substance capable of absorbing and combining with the acid vapours to the immediate gaseous products of the destructive distillation. By reference to

a former page, it will be seen that apertures are left in the meiler at different heights from the ground for the discharge of the gaseous products; these are connected, upon M. Paur's plan, with pipes that connect them with receivers about 3 or 4 feet high and 14 inches in diameter, containing layers of lime, carbonate of lime, or carbonate of soda. The products of the distillation in passing through these are deprived of acetic acid, the carbonic acid of the carbonates being displaced, and crude acetates of lime or soda at once obtained. The heat in the receivers rises considerably, but not sufficiently to decompose the acetates, although great part of the tarry vapours is expelled. No means of condensation or subsequent evaporation of the condensed products are here required, while the crude acetates may be purified by the ordinary processes.

The forms of apparatus very generally employed on the Continent for obtaining both charcoal, tar, and vinegar, are those of Reichenbach and Schwartz.

Reichenbach's kiln, the arrangement of which may be seen in Fig. 201, is calculated to contain 60 stacks and more of wood, which is built up round the two pipes *a b c d*, and *m n o p*, so as completely to fill the kiln. These pipes are furnished with iron rings at intervals, which prevent the wood, with which the kiln is filled, from coming into actual contact with them; they are 1 to 2 feet wide, and are intended for heating the kiln, being

FIG. 201.

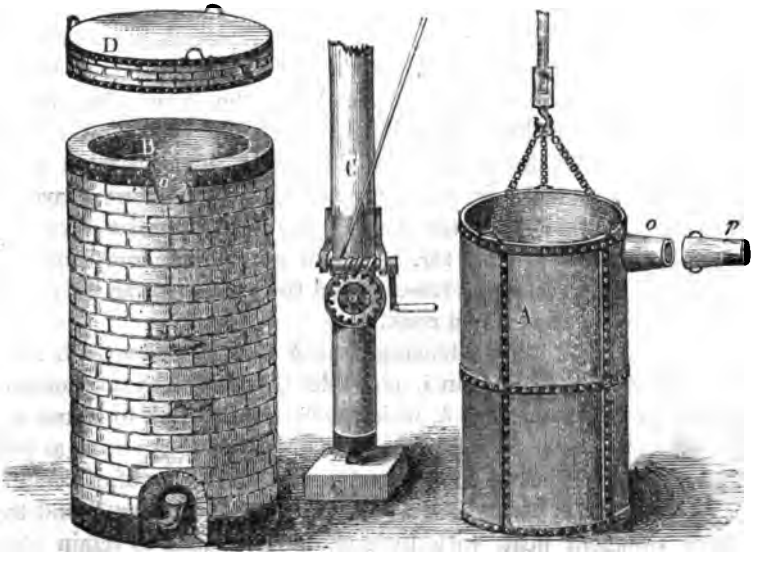


in fact continuations of the chimney-flues from two fires, situated the one below *p* and the other below *d*, but which are not represented in the drawing: the smoke and gases from the flues escape at *a* and *m*. Both pipes are heated to redness, and the charring commences from the entire surface of the pipes. The volatile products escape at the bottom of the kiln partly through the aperture *x* into the tube *f g h*, and partly through the aperture *y* into a similar tube, both of these uniting in a common pipe *i k* leading to the coolers. The wood having been introduced into the kiln from above, the top is closed up with cast-iron plates, covered by a layer of sand. The inner walls of the kiln are constructed of fire-brick, the outer of hewn stone, between which is enclosed a layer of sand to prevent the loss of heat by radiation.

The plan employed in Sweden, and known as Schwartz's process, has been already described at pp. 80 and 81.

When wood is distilled for the special purpose of the acid which it yields, the operation is always conducted in cylindrical iron vessels, heated on the outside. In France the vessels employed, as shown at *A* in Fig. 202, are 3 to 4 feet in diameter, and 6 to 8 feet high, having a capacity of from 40 to 100 cubic feet: they are lowered or raised in the furnace *B*, by means

FIG. 202.



of the crane *C*. Two of the retorts *A* are employed in connection with each furnace, the one being emptied and recharged while the other is at work in the furnace. The upper end of the cylinder is in the form of a lid, and can be removed as soon as the cylinder is cold; the charcoal is then removed, and a fresh charge of wood packed in as closely as possible, so as to fill the cylinder completely, when the lid is replaced and fixed down with wedges. The furnace lid *D* is removed when a fresh cylinder is introduced, and the neck *o* of the freshly-charged cylinder allowed to fall into the groove *o'*, when the lid is again replaced. The cylinder rests on the top of an arch which separates the fireplace from the body of the furnace. The flame passes through a number of apertures in this arch to the bottom of the cylinder, traverses the sides of the latter in a spiral manner, and escapes into the chimney by an aperture below the lid of the cylinder, after reverberating over and heating the lid. By the exchange of cylinders heat and fuel are economised, as it is not necessary to allow the furnace to cool. The heat acting on the entire surface of the cylinder first expels aqueous vapour, and when the vapour becomes thick and smoky, the neck *o* is connected with the pipe leading to the condenser by means of the connecting piece *p*.

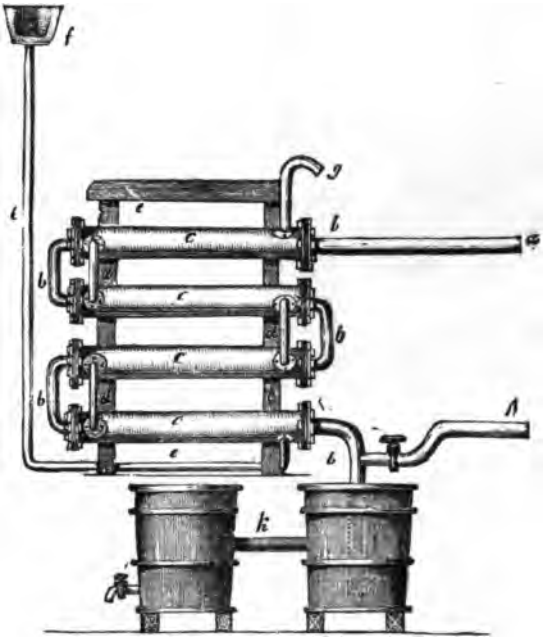
The volatile products escape through the neck *o* and connecting piece *p* into the zig-zag condensing pipe *b*, Fig. 203, which is supported by the frame *e*, and between the outside of which and the pipes *c c c* a current of cold water is kept constantly flowing. The cold water enters through *f* and *l* to the lower pipes first, then through the knee-shaped joints *d d*, and passes off warm through *g*. All the products condensed by this apparatus first enter the tar vessel *i*, in which the tar occupies the lowest layer: the portions that flow over through the pipe *k* consist of crude vinegar with a very little tar. The tar is removed from time to time by a pump from the vessel *i*, and the wood-vinegar is drawn from the other vessel by a cock.

The mouth of the condensing pipe *b* being constantly below the surface of the liquid in *i*, no outlet is afforded to the uncondensed gases but the pipe *h*, which carries them back to a rose *n*, placed in the ash-pit below the fire (Fig. 202). As soon as all the air is expelled from the apparatus, and all danger of explosion is thus removed, the gases are ignited, and are then found to afford sufficient heat, with little or no extra fuel, to retain the

cylinder at the proper temperature, while by this arrangement the noxious odour proceeding from the tarry vapours with which they are saturated, is entirely destroyed.

The receivers are often constructed of brick instead of wood,

FIG. 203.



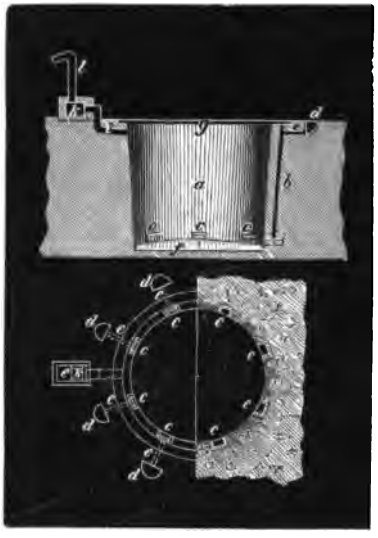
and where water is scarce the cooling is effected by the air, the gases being carried through a series of vessels arranged on the plan of Woulff's bottles.

In this process eight hours are required for working off one charge of about 5 steres, or 162 cubic feet of wood.

A similar arrangement is shown in Fig. 164, p. 294.

The following system of charring in pits, introduced by Chabeaussiere, is carried out in Norway, Sweden, and Russia, in connection with the production of tar. A pit *a* is sunk 9 feet deep, 10 feet in diameter at the surface, and 9 feet at the bottom; the sides are made good, and covered with clods. The air is supplied by a flue *b*, which communicates with the bottom of the oven by the air-channels *c c*, and in order to prevent the stoppage of the upright flue *b* by the falling

FIG. 204.



in of any of the materials on the surface, the air passes in at *d* along a small pipe *e*. The bottom *f* is formed of clay, and slopes towards the sides. The upper edge *g* is faced with stone to support a cast-iron cover, which has four small openings. The wood is piled in this pit in the same manner as in the meiler, and the volatile products pass off by a pipe *l*, the liquid portion condensing in a stone vessel *k*.

The pit is charged with small pieces of pine- or fir-wood, and ignited by burning charcoal through a perpendicular flue in the centre.

The usual process adopted in England for distilling wood for pyroligneous acid is to heat it in cast-iron cylinders or retorts, from 6 to 10 feet long and from 3 to 4 feet in diameter, laid horizontally in brickwork, with their ends projecting a little. At one end there is a door on hinges placed in the centre of the front of each cylinder, by which the wood is introduced and the charcoal withdrawn; the other end is attached to a condenser of copper or iron. One fire is sufficient to heat two or three cylinders, the flame playing around them, the under-surface of the cylinder being protected by fire-tiles from the direct and too powerful action of the fire. They are heated during the day and allowed to cool during the night, and the distillation being complete, the doors of the retorts are opened, and the charcoal raked out into sheet-iron boxes, which can be made air-tight, to cool, and the retorts again charged with wood. The charge of wood varies, of course, with the size of the retort. The average is from 6 to 8 cwt., though some retorts are made to hold as much as two tons of wood, as at the Risca works in Monmouthshire.

The time required for distillation increases with the size of the retort and amount of charge, and twenty-four hours is allowed for the large-sized cylinders.

Wrought-iron chests of a square form are sometimes used,

particularly for light brush-wood, in lieu of the cylinders, which are placed in suitable ovens.

The uncondensed gas is used as fuel. The coal required to distil 1 ton of wood is about 7 cwt., and the average liquid product from the same weight of wood is 124 gallons, the pyroligneous acid being 6° Twaddell, or 1.030 specific gravity.

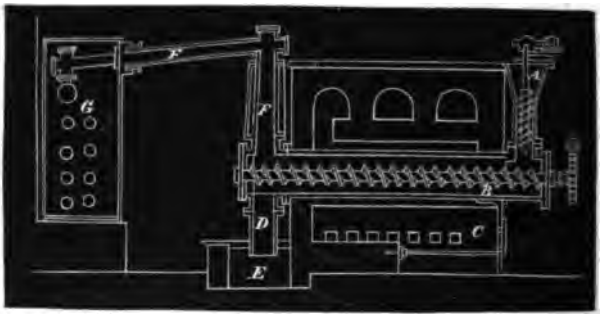
The heat required to distil over the pyroligneous acid is not very considerable; but towards the end of the operation the heat is increased so as to render the cylinder red-hot, and the time when the operation is completed is ascertained by the colour of the gas flame. At first it is of a reddish yellow, then it becomes blue, and finally it is quite white. There is another mode by which the workman judges of the completion of the process. A few drops of water are allowed to fall on that part of the pipe close to the furnace which is not surrounded with water. When the evaporation takes place without noise the distillation may be said to be finished.

The most recent and ingenious improvement in the manufacture of pyroligneous acid is that for which a patent was taken out by the late Mr. A. G. Halliday, of Manchester. The process consists in effecting the destructive distillation of waste materials, such as sawdust and spent dye-wood, by causing such substances to pass in continuous motion through heated retorts by means of suitable machinery. Fig. 205 shows an elevation and longitudinal section of the apparatus employed. The minutely divided state of the materials precludes the possibility of effecting their distillation by the ordinary way, as that portion of the material in immediate contact with the retort becoming charred, the non-conducting property of the charcoal prevents the heat from penetrating into the interior.

FIG. 205.

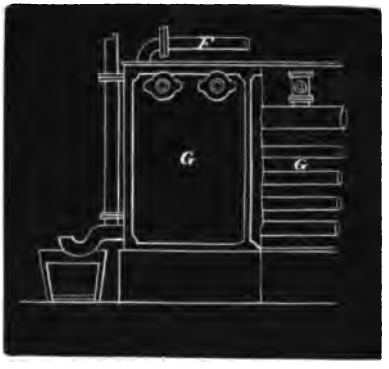
The saw-dust or spent dye-wood from which the pyroligneous acid is to be distilled, is introduced into a hopper, *A* (Fig. 206),

FIG. 206.



in which vertical screws or worms revolve, conveying the material (regulating at the same time the supply) to the retorts *B*, placed in a horizontal position and heated by means of a furnace *C*, and in which retorts revolving screws or worms keep the material in constant agitation, moving it at the same time forward until the whole is completely carbonised and all the pyroligneous acid evolved. The charcoal thus formed falls through pipes *D*, dipping into a vessel of water *E*, or into an air-tight vessel, and from which it may be withdrawn through a door at the side. The pyroligneous acid escapes by the pipe *FF*, and is condensed in the usual way in the condenser *G* (Fig. 207).

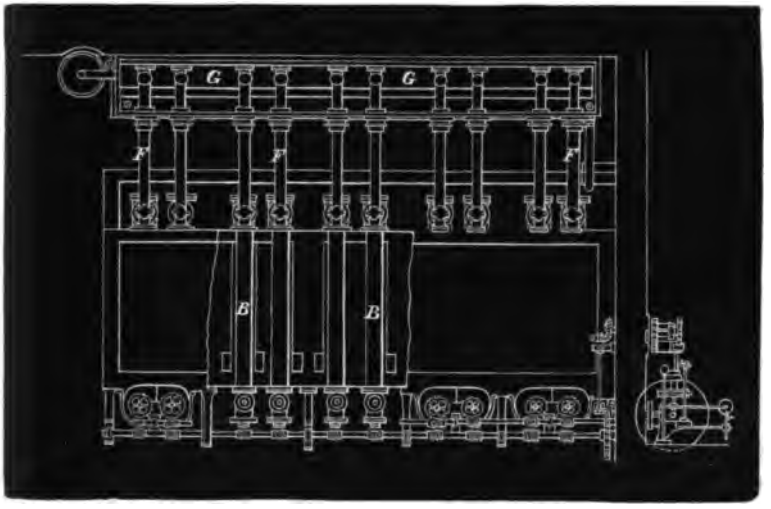
FIG. 207.



By this process the spent dye-woods, which have proved a source of annoyance and expense for their removal to the manufacturers of dye-wood liquors and dyers, can be manufactured into valuable products, and these spent woods yield as much pyroligneous acid as oak, beech, or birch. The retorts required are only 14 inches in diameter, and 8 of these retorts produce in twenty-four hours as much acid as 16 retorts 3 feet in diameter upon the old system.

Fig. 208 shows a plan of the entire apparatus, and Fig. 209 an elevation of the gearing employed. The charcoal obtained is in

FIG. 208.



an excellent state for deodorizing, and is extensively used for that purpose. One large manufacturing concern in the neighbourhood of Manchester, employing upwards of 1000 workpeople, use it for the urinals on their works, and find that it not only does away with all unpleasant odour, but, as charcoal in this state takes up 2½ times its weight of urine, they find this a ready and economical way of carrying this valuable manure to the land.

FIG. 209.

In the manufacturing districts of Lancashire and Yorkshire, where such immense quantities of dye-wood are employed, we have by this process an economical means of converting the waste material into charcoal, and obtaining the pyroligneous acid at the same time.

In working Mr. Halliday's patent 6 stills require an engine-power of from 2 to 3 horses to work them; 8 stills work up

22 tons of ordinary sawdust per week, running day and night shifts, and the produce is:—

2484 gallons pyroligneous acid, at 8°, Twaddell,
240 gallons tar,
4 tons charcoal.

The consumption of coals is about 7 tons, while the wear and tear is trifling. Mr. Halliday estimates the value as follows:—

	£.	s.	d.		£.	s.	d.
22 tons sawdust	1	2	0	Pyroligneous acid, at 1s.2d. per degree per gallon,— say 3s. on 2484 gallons...	31	1	0
7 tons coals at 5s.	1	15	0				
4 men at 15s.	3	0	0	240 gallons tar at 3d.	3	0	0
Wear and tear, interest, management and profit	29	4	0	4 tons charcoal	1	0	0
	£35	1	0		£35	1	0

Heated steam has been employed by Messrs. Solomans and Azulay for charring the waste substances mentioned above, the heat of the condensable products being employed in traversing a coil of pipes to heat the solutions to be evaporated or distilled.

Stolze, in his excellent essay on pyroligneous acid, has given the results of numerous experiments in reference to the quantities of acid, oil, and charcoal, from different kinds of wood, taken in equal weights and equally dry. He found that 1 lb. yielded from $5\frac{7}{8}$ to $7\frac{1}{2}$ oz. of oil and acid, and that the difference was due to the presence of resin, albumen, gluten, gum, &c., and not to a difference in the fibre; for, after extracting these various ingredients by water, alcohol, &c., 1 lb. of the wood invariably yielded $7\frac{1}{2}$ oz. of acetic acid.

The following Table from Stolze, and two others, will give some idea of the yield of different woods. All these woods were dried at 100° C. (212° F.)

One Pound of Wood.	Weight of Acid.	1 oz. of Acid neutralized pure Bicarbonate of Potash.	Weight of Empyreumatic Oil.	Weight of Charcoal.
	oz.	grains.	oz.	oz.
White Birch	7⅛	55	1⅜	3⅞
Red Beech	7	54	1⅛	3⅞
Large-leaved Linden	6⅞	52	1⅞	3⅜
Oak	6⅞	50	1⅛	4⅛
Common Ash	7⅛	44	1⅜	3¾
Horse Chesnut	7⅜	41	1⅜	3⅝
Lombardy Poplar	7⅜	40	1⅜	3¾
White Poplar	7⅜	39	1¼	3¾
Bird Cherry	7	37	1¼	3⅜
Basket Willow	7⅜	35	1⅛	3⅛
Buckthorn	7⅛	34	1⅜	3⅛
Logwood	7⅛	35	1⅛	2
Alder	7⅜	30	1⅛	3⅛
Juniper	7¼	29	1¼	3⅜
White Fir	6⅝	29	2⅛	3⅜
Common Pine	6¾	28	2⅞	3⅛
Common Savine	7	27	1⅞	3⅜
Red Fir	6⅜	25	2¼	3¾

Wood Employed, 84 lbs.	Charcoal produced.	Crude Liquor.	Uncondensed Gas.	Real Acetic Acid.
	lbs.	lbs.	lbs.	lbs.
Birch	24	46	14	3.06
Young Oak	26	39	14	3.06
Hawthorn	20	27	37	3.73
Ash	23	48	13	2.45
Birch	23½	45	15⅓	1.86
Elm	21½	45⅓	17	2.26
Alder	20	48	16	1.86
Willow	18	49	17	0.77

Wood, 3 cwt.	Crude Liquor.	1 lb. Saturated Bicarbonate of Potash.	Brown Acetate of Lime.	Charcoal.
	lbs.	grains.	lbs.	lbs.
Apple Tree	200	610	18	70
Ash	190	792	22	90
Oak	190	815	24	91
Beech	180	960	25	84
Elm	180	800	16	70
Maple	145	640	20	77
Walnut	150	750	15	72
Birch	120	1130	13	70

From the above it is evident that the saturating power is no criterion of the yield of acetate of lime, the weight of the latter being increased or diminished by the larger or smaller quantity of tar contained in the liquor. As a general rule, 1 ton of wood yields 140 lbs. of dark acetate of lime.

The amount of produce from the French process, in which the cooling apparatus is not of the most perfect description, is estimated generally at 33 per cent of the wood in crude pyroligneous acid. Kestner obtained from 100 cubic feet of wood 236 kilogrammes (=519.2 lbs.) of charcoal, and 540 litres (=118 gals.) of crude vinegar, corresponding to 400 litres (=88 gals.) of commercial vinegar of 7 per cent actual acid. According to other accounts, 100 lbs. of wood afford 25.5 lbs. of charcoal, 59 lbs. (about 30 litres) of acid of 1.027 sp. gr., and 9 lbs. of tar, leaving 6.5 lbs. as the weight of the uncondensable gases.

The crude pyroligneous acid, which separates spontaneously from the tar in the receiver, is a dark-brown-coloured liquid with an empyreumatic odour. The pyrogenous resin and extractive matter which are the sources of colour, amount to 6 per cent, according to Stolze. These substances, although products of dry distillation, are not themselves volatile, and should be capable of removal by redistillation; they are, however, accompanied in the vinegar by a volatile empyreumatic oil, which passes off on a second distillation, leaving the resins behind; the distilled product is colourless at first, but speedily again becomes yellow, in consequence of the oxidation of the oil to resin in contact with the air. Repeated distillation only partially removes this oil. 16 parts of crude pyroligneous acid yield 14 parts of colourless distillate, 1 part, towards the end of the operation, of very impure dark-coloured vinegar, and 1 part of resin and extract. The redistillation of the crude acid liquor is carried on in copper stills; the first, or more volatile portions, being collected apart, as they contain the wood-spirit, which will be noticed immediately.

After the spirit has distilled over, the distillation is either continued, to form, with the distilled acid, brown sugar of lead or grey acetate of lime, or the crude acid is merely supersaturated with lime to form the black acetate, or, in the calico-printing districts, the black acetate of lime liquor. After settling, it is boiled with a small portion of sulphate of lead, which takes down a great portion of the colouring matter with it. When this

acetate of lime liquor has settled, it is in a proper state for the formation of the red liquor, or mordant for reds, extensively used by calico-printers to fix the red colouring matter of madder on cloth.

Purification of the Acid. Production of Acetate of Soda.—Two methods are followed in the purification of wood-vinegar from the pyrogenous substances with which it is associated, both of which admit of several modifications. By the one, the pyrogenous substances are destroyed by oxidizing agents; and three modifications of this plan have been proposed by Stoltze:—1. The crude acid is redistilled to dryness, and to a hogshead of the distillate 12 lbs. of peroxide of manganese are added, and the mixture is allowed to stand for twelve hours at a temperature of 90° C. (194° F.), when it is mixed with 90 lbs. of well-burnt wood-charcoal, and allowed to remain at the same temperature for another twelve hours. It is then redistilled, a portion remaining as acetate of manganese in the still. 2. To the same quantity of distilled acid 7½ lbs. of manganese and 11 lbs. of vitriol are added, and the mixture is treated as in the first process. 3. A hogshead of distilled acid is mixed with 9 lbs. of common salt, 3½ lbs. of manganese, and 5½ lbs. of sulphuric acid, and the mixture distilled as before. Although the product from these processes is colourless, it still possesses a slight empyreumatic odour, and must be digested for twelve hours with one-fifth of its weight of wood-charcoal; and when sulphuric acid is employed, requires an addition of manganese, and redistillation to remove sulphurous acid.

Although Stoltze obtained pure acetic acid by these processes, they do not appear to have been practised by manufacturers; and the other method, which consists in neutralizing the crude acid with a base, and subsequently decomposing the salt thus formed by a stronger acid, and distillation, is universally adopted. The rectified crude acid is neutralized by chalk and a little milk of lime, and small portions tested, after effervescence has ceased, to ascertain its neutrality. Fresh portions of tar separate, and are removed by skimming, when the effervescence ceases. The clear liquor is then evaporated to a sp. gr. of 1.114, and, while hot, a saturated solution of sulphate of soda added, sufficient to decompose the acetate of lime; and finally, a little carbonate of soda, to remove the last portions of lime. Every 160 parts of dry acetate of lime require about 160 parts of dry sulphate of soda.

This mixture is well stirred, and allowed to settle; it deposits sulphate of lime, and a double salt of sulphate of soda and lime, while acetate of soda remains in solution.

The solution is evaporated in iron or copper boilers until it attains a sp. gr. of 1.356, and allowed to settle for about twelve hours, and the clear liquor run into iron or earthenware vessels to crystallize. After three or four days the mother liquor is run off from the crystals, and either boiled down to crystallizing strength, or added to a fresh portion of liquor. When the mothers become too foul for use, they are boiled down to dryness and calcined, yielding acetone and carbonate of soda. The crystals are next melted in shallow cast-iron boilers at a temperature of 500° F., great care being taken to prevent the destruction of the acetic acid by agitation. They first fuse in their water of crystallization, which is gradually evaporated, and the tarry matter rendered insoluble by carbonization. When the frothing ceases, the liquid is ladled out into moulds, and afterwards digested with water, until the solution has a sp. gr. of not more than 1.116, as the carbonaceous matter will not settle from stronger liquors. In some cases the melted salt is thrown at once into water, without the use of moulds. The clear liquor is now evaporated to sp. gr. 1.242, and crystallized. The loss by fusion and crystallization amounts to some 6 or 8 per cent. The above quantities yield about 160 parts dry, or 260 parts crystallized acetate of soda.

About 200 lbs. of the crystallized acetate of soda are now introduced into an iron or copper still, with a copper capital, and 119 lbs. of concentrated sulphuric acid. The heat developed by the chemical action which ensues being apt to decompose acetic acid, the oil of vitriol is gradually added in successive portions. The best mode of heating is by high-pressure steam. The product is nearly 279 lbs. of acid of sp. gr. 1.052, with a light green tint from the presence of copper. The acid, when required for table use, is subjected to a second distillation in a copper still, with a capital and worm of silver, glass, or porcelain. The last trace of empyreuma is removed, on the continent, by distilling again from animal charcoal, or by passing the acid through a filter of animal charcoal previously deprived of bone-earth. The acid of 1.052 is reduced to pickling or revenue-proof strength by five times its weight of water; a little burnt sugar is often added to give colour to the acid, and sometimes acetic ether for its aroma.

There are several variations of the above process for purifying

wood-vinegar, which deserve notice. The sulphate of soda is sometimes dissolved in the rectified acid, by which means a portion of essential oil is thrown to the surface, and may be skimmed off, and carbonate of lime added afterwards, as long as effervescence takes place. Again, instead of the double decomposition of acetate of lime and sulphate of soda, some manufacturers neutralize the rectified acid directly by crude soda or sulphuret of sodium, which is believed to be more economical by saving time and fuel. Strong acid is also prepared by drying and gently torrifying the acetate of lime, and decomposing it in iron cylinders by sulphuric acid, as in the manufacture of muriatic acid. 208 parts acetate of lime, and 133 parts of oil of vitriol, yield 270 parts of acetic acid of sp. gr. 1.05; but the acid is very much contaminated with empyreumatic oils. The acetate of lime being much less stable at a high temperature than acetate of soda, a greater loss is sustained in the torrification if the temperature is raised at all high, although this is diminished, according to Ackermann, by the addition of an extra quantity of hydrate of lime to the salt before heating.

Another process, by which an impure acid may be obtained from the dry soda salt without distillation, depends upon the difficult solubility of sulphate of soda in strong acetic acid. In order to prevent an admixture of oil of vitriol, about 1 per cent less is employed than would saturate the soda in the acetate, and to avoid loss of acid which might arise from evaporation if the vitriol were intimately mixed with the fused acetate, the vitriol is poured in at once upon the salt without stirring: the latter being lighter comes to the surface, and the decomposition proceeds slowly from the points of contact. By cautious stirring the process may be accelerated, and is still quite under command. After the decomposition is completed, the sulphate of soda falls down as a crystalline powder, and the liquid acid may be syphoned off. Acid thus prepared contains about 1 per cent of sulphate of soda, and from 3 to 5 per cent of acetate of soda in solution.

Völckel recommends the use of hydrochloric acid in place of sulphuric acid for decomposing the crude acetate of lime. The crude acetate of lime is separated from the tarry bodies which are deposited on neutralization, and evaporated to about one-half its bulk in an iron pan. Hydrochloric acid is then added until a distinct acid reaction is produced on cooling; by this means

the resinous bodies are separated, and come to the surface of the boiling liquid in a melted state, whence they can be removed by skimming; while the compounds of lime with creosote and other volatile bodies are likewise decomposed and expelled on further evaporation: from 4 to 6 lbs. of hydrochloric acid for every 33 gallons of wood-vinegar is the average quantity required for this purpose. The acetate having been dried at a high temperature on iron plates, to char and drive off the remainder of the tar and resinous bodies, is then decomposed, in a still with a copper head and leaden condensing-tube, by hydrochloric acid. To every 100 lbs. of salt, about 90 to 95 lbs. of hydrochloric acid of sp. gr. 1.16 will generally be found sufficient, although it is sometimes necessary to make a special trial on a small scale to ascertain the exact quantity required. The salt dissolves in the acid with a dark brown colour, and resins come to the surface, which can be removed to some extent before the distillation commences. The acid comes over at a temperature of from 100° to 120° C. (212-248° F.), and is very slightly impregnated with empyreumatic products, while a mere cloud is produced in it by nitrate of silver if the proper proportion of hydrochloric acid has been employed. The sp. gr. of the product varies from 1.058 to 1.061, and contains more than 40 per cent of anhydrous acetic acid: acid of this strength being seldom required, it is well to dilute the 90 parts of hydrochloric acid with 25 parts of water. These proportions then yield from 95 to 100 parts of acetic acid of sp. gr. 1.015. Or 33 gallons of crude wood-vinegar will produce 60 lbs. of acetic acid of the above strength.

Redistillation from a small quantity of carbonate of soda, peroxide of manganese, or from 2 to 3 per cent of bichromate of potash, renders the acid perfectly pure, and at the same time removes any hydrochloric acid which may have passed over with it. The redistillation may be carried on with a copper still and leaden tube, provided air be excluded, and the first and last portions of the distillate be rejected. These are liable to contain acetate of lead, but the greater part of the acid is free from that salt. This process is recommended on the score of economy and greater purity of product. The volatile empyreumatic bodies are more easily removed by the addition of hydrochloric acid to the impure acetate of lime, than when solution of chloride of calcium is used for that purpose, and a very high temperature in

drying the acetate is not so requisite. The chloride of calcium melting easily in the still, enables the whole of the acetic acid to be evolved at a lower temperature than when vitriol is employed, which forms, in combination with lime, a hard incrustation on the bottom of the still, which requires to be heated to redness to remove the whole of the acetic acid, and speedily renders the still useless. The resinous bodies towards the end of the operation likewise decompose the sulphuric acid and the sulphate, giving rise to sulphurous acid, sulphuretted hydrogen, and other products which render the acetic acid impure.

If binacetate of potash is heated in a retort, it commences to melt at 148° C. (299° F.), and to boil at 200° (392° F.), at which temperature, under a gradual rise, glacial acetic acid, or monohydrated acetic acid, distils over, neutral acetate of potash remaining in the retort. Melsens recommends a modification of this process for the production of strong acetic acid. The plan proposed is to distil moderately dilute acetic acid with neutral acetate of potash, collecting in a separate vessel the first weak portions of acid which pass over.

The greater portion of the pyroligneous acid prepared in this country is employed in the manufacture of the acetates for the use of dyers and calico-printers, and only a small portion is purified for household purposes.

The strongest hydrated acid is solid at 17° C. (63° F.); above that temperature it melts to a colourless liquid, and has a sp. gr. of 1.063. The composition of the acid is then $C_4 H_3 O_3$, HO. It possesses a characteristic odour, a very sharp taste, and is as corrosive as the most powerful mineral acids. Acetic acid boils at 120° C. (248° F.); it is soluble in all proportions in water, and its vapour burns with a blue flame. The strong acid, mixed with about 30 per cent of water, increases in density to 1.079, which is its maximum density; with more water, this is again diminished. The following Table by Mollerat clearly shows that specific gravity can never be taken as a test of the strength of acetic acid:—

Density.	Quantity of water to 100 of the monohydrate.
1.0630	0.0
1.0742	10.0
1.0770	22.5
1.0791	32.5

Density.	Quantity of water to 100 of the monohydrate.
1.0763	43.0
1.0742	55.0
1.0728	66.5
1.0558	97.5
1.0637	108.5
1.0630	112.2

The safest mode of ascertaining the real strength of the acid is by observing the quantity of pure carbonate of baryta which it requires for saturation. It is necessary, however, to test for the presence of mineral acids in the first instance; as these, particularly sulphuric acid, are often employed to increase the acidity of weak vinegar, and the operation must be conducted in the cold.

Acetic Acid.—Carbonated alkali, as used in acetimetry generally, is not adapted for testing the strength of acetic acid, the blue of the litmus being reddened by the liberated acid long before the acid is saturated, and if heat is applied a loss of the volatile acid ensues. Caustic alkali is equally ill-adapted, as it is difficult to keep it caustic.

When marble is used, the impossibility of bringing the substance to the same state of dryness before and after the experiment is a source of error. The method by ascertaining the amount of pure dry carbonate of baryta taken up by the acid, is exact but tedious, as the operation must be carried on with a cold solution.

Mr. Williams recommends a solution of lime in sugar of known strength, which is easily ascertained by an ordinary alkalometric experiment. The solution of saccharate of lime, of which five divisions, measured in the ordinary burette, correspond to one grain of acetic acid, is found to keep for a long time without appreciable change. This solution is gradually added to 50 gr. of the specimen dissolved in about 2 oz. of water, when the indications of litmus will show the amount of acid accurately to one-fourth of a per cent.

Alcohol, according to Pelouze, has a remarkable property of modifying the affinity of acetic acid, so that the mixture of the two no longer reddens litmus-paper, and will not decompose certain carbonates.

M. Gerhardt has succeeded in preparing anhydrous acetic acid

$C_8 H_6 O_6$, or $2 (C_4 H_3 O_3)$, by mixing dry acetate of potash with about half its weight of chloride of benzoyl, and applying a gentle heat. The liquid product is redistilled, and forms a limpid liquid, boiling at a constant temperature of 247°.5 F. This substance is heavier than water: it acquires an acid reaction in moist air, and forms at once a hydrate with hot water.

The following compounds of this acid are generally prepared with the product from the distillation of wood:—

Acetate of Lime.—Two kinds of this salt are manufactured in the wood-vinegar works, known respectively as brown and grey acetate. The former is prepared by saturating the crude acid, after the pyroxylic spirit has been removed by distillation, with powdered chalk or slaked and sifted lime,—a small excess being employed, which is found to aid the separation of the tar. The grey acetate is prepared in the same manner with the distilled acid. The solutions of acetate of lime are evaporated over the naked fire, or by steam heat, the tarry scum being constantly removed from the surface. As the crystals form, they are removed by the skimmer, and placed in baskets over the evaporating vessels to drain. They require to be carefully dried at a gradually increasing temperature up to 257° F., and the operation is best performed in a close chamber, to prevent loss of acid and secure them from any sparks, which, if allowed to fall on the dry acetate, ignite it and destroy the whole. A much purer product is obtained by redissolving the dried acetate, and crystallizing again.

Brown Acetate of Lead.—Crude pyroligneous acid is much used for the manufacture of brown acetate of lead, in the following manner. The redistilled pyroligneous acid is saturated in a tub with litharge, and the oxide of lead not dissolved allowed to subside; the clear liquor is decanted into a copper boiler, and evaporated, until a drop, let fall upon a cold stone, crystallizes or sets hard, which may take place at sp. gr. 1.980: about three times its weight of water is now added while boiling, the solution being constantly stirred. By this treatment a considerable quantity of pyrogenous matter may be skimmed off as it rises to the surface. When this is removed, the evaporation is continued. If the solution be still too much coloured, more water must be added. Practice soon enables the workman to know when the evaporation is sufficiently advanced. A common test

is to rinse the ladle, which is used to skim off the tar from the solution, through the liquid, and observe how many drops of solution fall from it before it assumes a stringy appearance; if ten or twelve only fall, then it is sufficiently strong. Another plan is to take the specific gravity of the liquid, which may be considered fit for crystallizing when the density is above 1.980.

The liquid is now run into the crystallizing vessels, which may be made of sheet iron, and are generally 5 feet by 3½ feet, and 6 inches deep, the sides being bevelled, or sloping outwards from the bottom.

After becoming sufficiently firm, the sugar of lead is taken out by inverting the vessel on a cloth, and is subsequently dried.

White Acetate of Lead.—In preparing this salt acetic acid is saturated in a tub with litharge; every degree of Twaddel's hydrometer shown by the acid must be raised to 15° Tw. by the addition of litharge—*e. g.* acetic acid of 2° Tw. would be stirred with litharge until the solution of acetate of lead marked 30° Tw. The solution is made in the cold in a wooden tub, and constantly agitated until it acquires the requisite strength. At this point, and while the liquid shows a slight acid reaction, the tub is covered up to allow the impurities to settle. The solution is then transferred into a copper boiler, and evaporated down to about 160° or 180° Tw. at boiling heat. The pan is again covered up for the subsidence of any impurity; the liquid then drawn off, poured into earthenware vessels holding about a gallon each, and allowed to crystallize. The crystals are drained, dissolved in a quantity of water merely sufficient for this purpose, and recrystallized. These crystals are dried at about 80° or 90° F.

A piece of lead, added to the solution while evaporating, throws out any copper which it may contain, while it assists in preserving the copper boiler from the action of free acid.

According to Dr. Ure, 112 lbs. of good Newcastle litharge, with 127 lbs. of acetic acid of sp. gr. 1.057, yield 180 lbs. of sugar of lead. A ton of Welsh litharge, with the acid from a ton of acetate of lime, produces 28 to 30 cwts.; or a ton of best Newcastle litharge, with the acid from 1½ tons of acetate of lime, produces 33 cwts. of acetate.

In Germany, thin sheet-lead, or the residues from the white-lead manufacture, are exposed to the alternate action of air and

strong acetic acid, in a series of vessels ranged one above another. The acid being first introduced into the uppermost, is allowed to flow consecutively into the lower vessels, remaining about half an hour in each. The metal, under these circumstances, becomes speedily oxidized at the expense of the air, much heat being generated; and after having passed twice through eight of these vessels filled with lead, the acid is sufficiently saturated with the oxide of the metal to be evaporated, and the salt crystallized.

A patent was also secured some time ago for passing the vapour of the acid into close vessels containing a number of perforated shelves on which litharge was spread. In passing through these the acid becomes saturated with the oxide, and the solution of the acetate falls down and is concentrated in other vessels by the heat of the waste steam which issues from the top of the litharge chambers.

Acetate of Iron, or Iron-Liquor.—This important mordant may be prepared by direct action, or by double decomposition.

The first method is generally preferred. It consists in digesting the crude pyroligneous acid with clean malleable iron turnings, or old hoop iron. It is found necessary to change the liquor from one vessel to another every alternate day, or to place a series of vessels so arranged that the liquor shall pass from one to the other until it is saturated. This point is ascertained by the appearance of froth on the surface, or by the hydrometer indicating that the liquor ceases to increase in strength, which is usually from 17° to 18° Tw. The liquor is now boiled down to 24°, which is the strength required by the calico-printers.

This mordant may also be obtained by double decomposition, for which crude acetate of lime and copperas are alone used.

The proportions employed are as follows:

75 galls. acetate of lime, at 16° Tw.
400 lbs. copperas.
100 galls. water.

The copperas is dissolved in water by heat, and the acetate of lime added while the whole is agitated. The clear liquor is decanted off from the precipitate. The liquor, however, made in this way is inferior to that made by direct action, as the lime,

in combining with the pyroligneous acid, destroys the essential oils, which have a beneficial effect in the other liquor in retarding the too rapid oxidation of the iron on the cloth, and the colours, especially purples, are inferior.

The composition of this liquor varies in the proportions of protoxide and peroxide of iron and of acetic acid which it contains, and is sometimes adulterated with muriate and sulphate of iron. It easily parts with its acid, and hence its value as a mordant.

Acetate of Alumina, or Red Liquor.—Pure acetate of alumina is not employed as a mordant, but the substance known as Red Liquor, which is a compound of acetate of alumina with sulphate of alumina. This is prepared by mixing acetate of lead or lime with alum, ammonia-alum, or sulphate of alumina, in different proportions.

Instead of using 3 equivs. of acetate of lead, 570 parts, with 1 equiv. of alum, 475 parts, which would remove *all* the sulphuric acid in the alum, it is found that equal parts of each salt answer better, and in practice 3 of sugar of lead are employed for 4 of alum. According to the experiments of Kœchlin Schonch, it appears that acetate of alumina is not the only active agent in red liquor, but that the sulphate of alumina present plays an important part. While the goods upon which this mordant has been printed are drying, the acetic acid volatilizes, and the alumina of the acetate combines with the sulphate, forming subsulphate of alumina on the cloth, which constitutes the true mordant. It is unnecessary, as already stated, to decompose all the alum by acetate of lead, since the remaining salt acts as a base, as well as pure acetate of alumina, when the due proportions are attended to: as, for example—

16	parts	water by weight, or	32	galls.
4	„	alum „ „	64	lbs.
$\frac{1}{16}$	„	soda „ „	1	„
3	„	sugar of lead „	48	„

Kœchlin Schonch asserts, from his experiments, that it is less economical, and immaterial as regards depth and tone of colour, to employ 100 of alum to 125, or 75 acetate of lead; but Runge contends that such is not the case, and that it is more advantageous

to take 100 of alum to 120 of the acetate, but that the quantity of water in either case is important, and should not be the same as that employed by Kœchlin. Runge has not, however, taken into consideration the neutralization of a portion of the sulphuric acid by carbonate of soda, which, by bringing basic salts into action, materially changes the subsequent operation of drying, and undoubtedly fastens a larger amount of alumina on the piece than could be done without employing it. Although a portion of alum, in this case, may be washed out after drying, it is questionable whether the advantage of using so large a proportion of acetate of lead is not counterbalanced by its great expense.

In the Manchester district, the greater proportion of the red mordant is made by the double decomposition of alum by acetate of lime, which has nearly replaced the acetate of lead.

The ordinary proportions used are as follows:

1 gall. acetate of lime liquor at 13° Tw.
2½ lbs. alum.

The acetate of lime is heated to 160° F., and the alum is dissolved in this liquor. The usual strength in which red liquor is used is indicated by 17° Tw., or sp. gr. 1.085. Sulphate of alumina has been extensively employed in the manufacture of the red mordant, but unless this article is of uniform quality its use is attended with great risk.

Wood-Spirit; Pyroxylic Spirit; Wood-Naphtha.—The first product that distils over in the rectification of crude pyroligneous acid is essentially different in properties from the acid which follows, and is, as has already been mentioned, collected in a separate receiver. The product possesses at the same time a spirituous and empyreumatic odour, and a yellow colour, which becomes darker on exposure to the air; it consists, as might be conjectured from the nature of the process, of a mixture of substances more volatile than wood-vinegar, and varying with the mode in which the process of distillation is conducted, and the character of the wood operated upon.

Crude Wood-spirit, being a commercial article of some value, is always collected as a secondary product in the wood-vinegar works. As long as the distillate has a spirituous odour in dis-

tilling the crude vinegar, it is collected separately, or, as the spirit has a lower specific gravity than the acid, a hydrometer may be employed to mark the density at which it is desirable to change the receiver. From 10 to 15 per cent of the crude wood-vinegar is obtained on an average in the form of wood-spirit.

The composition of this crude spirit is not completely ascertained, but its most essential ingredients have been isolated and examined. Amongst these the most important are *hydrated oxide of methyl* $= C_2 H_3 O, HO$, or pure wood-spirit, a body belonging to the class of the alcohols; and the *acetate of methyl* (Reichenbach's mesite), which two comprise the greater proportion of the crude spirit: besides these, however, it contains lignone, acetone, aldehyde, xylite, water, ammonia, pyroxanthine, a yellow pyrogenous colouring matter, and empyreumatic oil.

The spirit requires purification for some of its applications, although this must not be carried too far, if it is required for dissolving the gums, shellac, sandarac, and mastic, as it will not act on the latter two unless there be a small portion of essential oil present. Lime is generally employed for this purpose; the lime removes the free acetic acid, decomposes the acetate of methyl, setting free the hydrated oxide, although this requires repeated digestion and distillation, and is even at last seldom complete. The pyroxanthine and empyreumatic substances are also precipitated by the lime in the form of a brown resinous mass. The spirit is repeatedly distilled in copper stills, often heated by steam from slaked lime, to which an addition of potash is sometimes made; the product always retains some essential oil, although it may be rendered so pure as not to become turbid when mixed with water. The product is much purer if the crude pyroligneous acid is saturated with lime in the first instance, before collecting the spirit. One ton of wood should yield about 2½ gallons of rectified spirit.

Mr. Scanlan states the sp. gr. of wood-spirit to be 0.828, and its boiling point 150° F. Dr. Ure gives the boiling point of wood-spirit of 0.870 sp. gr. as 144° F., and if it be brought to 0.832, it then boils at 140° F. Ure has also published the following Table, showing the relative quantities of wood-spirit in specimens of different specific gravities.

Specific Gravity.	Real Spirit per cent.	Over Excise Proof.	Specific Gravity.	Real Spirit per cent.	Over or under Proof.
.8136	100.		.9032	68.50	13.10
.8216	98.	64.10	.9060	67.56	11.40
8256	96.11	61.10	.9070	66.66	9.30
.8320	94.34	58.00	.9116	65.00	7.10
.8384	92.22	55.50	.9154	63.30	4.20
.8418	90.99	52.50	.9184	61.73	2.10
.8470	89.30	49.70			Under Proof.
.8514	87 72	47.40	.9218	60.24	0.60
.8564	86.20	44.60	.9242	58.82	2.50
.8596	84.75	42.20	.9266	57.73	4.00
.8642	83.33	39.90	.9296	56.18	7.00
.8674	82.00	37.10	.9344	53.70	11.00
8712	80.64	35.00	.9386	51.54	15.30
.8742	79.36	32.70	.9414	50.00	17.80
.8784	78.13	30.00	.9448	47.62	20.80
.8820	77.00	27.90	.9484	46.00	25.10
.8842	75.76	26.00	.9518	43.48	28.80
.8876	74.63	24.30	.9540	41.66	31.90
.8918	73.53	22.20	.9564	40.00	34 20
.8930	72.46	20.60	.9584	38.46	35.60
.8950	71.43	18.30	.9600	37.11	38.10
.8984	70.42	16.30	.9620	35.71	40.60
.9008	69.44	15.30			

Ure observes that the spirit obtained by distilling the crude liquors, without the addition of lime in the first instance, is always a better solvent of sandarach than that obtained by neutralizing the acid before distillation. It then contains less real spirit, and is rendered milky by water.

Wood-spirit is used to some extent in this country, in place of alcohol, in spirit-lamps; but the extensive introduction of gas for chemical purposes is gradually superseding both these fuels in the laboratory. For dissolving the volatile oils, fats, and resins, a spirit of great purity is required.

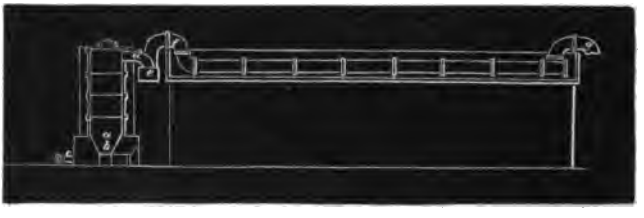
Acetone, or Pyro-acetic Spirit.—The acetates of lime and soda are sometimes submitted to dry distillation for the sake of the pyro-acetic spirit which they afford, and which is used to some extent for dissolving the gums employed in stiffening the bodies of hats. All the acetates yield a proportion of this spirit, but those which contain bases, the carbonates of which are not decomposed at a high temperature, afford the largest amount. The spirit comes over most abundantly at the end of the operation, and is always accompanied by empyreumatic oils and acetic acid. The temperature should be kept as low as

is consistent with the decomposition of the acetate. When acetate of lime is employed, 1 cwt. of the salt yields about 2 gallons of acetone. The crude product is separated from the oil which accompanies it, and is rectified by successive distillations over quicklime.

Acetone is a limpid colourless liquid of sp. gr. 0.7921 at 60° F., boiling at 100° F., and remaining fluid at 5°. Its composition is expressed by the formula $C_3 H_3 O$. It is soluble in water, alcohol, and ether, and burns with a white flame. Acetone is easily distinguished from pyroxylic spirit by means of chloride of calcium, which is quite insoluble in it, while wood-spirit dissolves and combines with it.

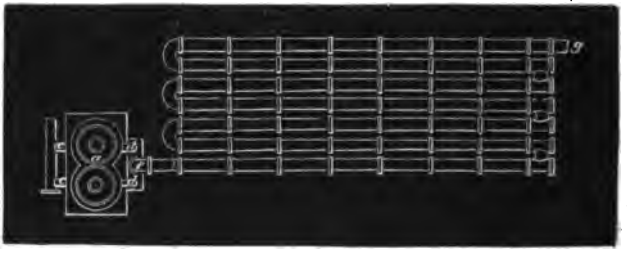
Production of Paraffine, Oils, Pyroligneous Acid, Pyroxylic Spirit, and Ammonia, from Peat.—A patent was obtained in the year 1849 by Mr. Rees Reece for a process to obtain certain products from peat, by which the bog lands of Ireland, hitherto a reproach, were to be converted into a mine of wealth to the country. The process, as patented by Mr. Reece, consists in burning peat in a blast furnace of similar construction to the iron blast furnaces, only closed at the top, and furnished with apparatus for carrying away and condensing the volatile products of distillation. Fig. 210 shows a sectional elevation of the blast

FIG. 210.



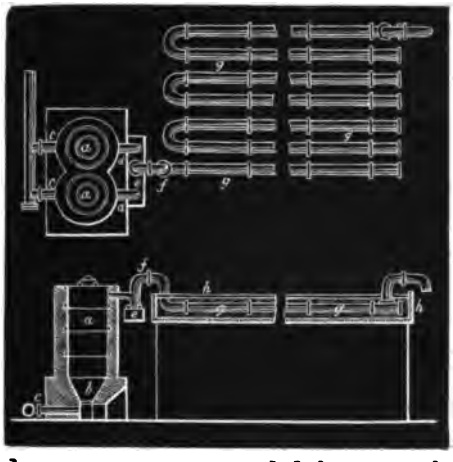
furnace, and Fig. 211 a plan of the pair of furnaces intended to work together with the pipes for condensing the products.

FIG. 211.



The drawings are taken from Mr. Reece's original specification. The furnaces and condensing apparatus, since erected on the Bog of Allen, near Athy, are somewhat differently constructed; the furnaces have more the shape of iron blast furnaces, are built of brick, 10 feet in diameter at the widest part, and encased in sheet iron, the mouths being furnished with a double cone, similar to that shown in Fig. 86, page 160. The condensers are not surrounded by water, but are upright, connected together two and two at the top, and terminating at the lower open extremities in a metal box, with a diaphragm, which serves as a recipient for the semi-solid tar, and, at the same time, as a valve for preventing the escape of the gases. It is calculated that 12000 feet of surface will be required to condense the products from 100 tons of peat. Scrubbers are erected at the end of the very extensive series of condensing pipes, in which the escaping gases are well washed with water, and the last trace of ammonia removed.

FIG. 212.



The furnaces being charged with air-dried peat, ignited at the bottom, and closed, the blast is applied, furnishing 3000 cubic feet of air per minute, which is the amount required for the distillation of 100 tons of peat in the twenty-four hours. The heat from the combustion of the peat in the lower part of the furnace is thus employed to distil the upper layers; the products of combustion, with the proceeds of the distillation, being forced forward by the blast to the condensers.

The crude products of the distillation are tar, water, and gas, the ashes of the peat fluxing, according to Mr. Reece, and flowing out as slag. The two former, the tar and water, are collected in tanks connected with the condensers, while the gas passes on through flues to the various boilers, evaporating pans, tar-stills, &c., where it is to be employed as fuel. From 100 tons of peat, 6 million cubic feet of mixed gases are said to be obtained, consisting of

carburetted hydrogen, free hydrogen, and carbonic oxide, some nitrogen and carbonic acid; 2 millions of cubic feet are calculated by the patentee as sufficient for carrying on all the operations connected with the manufacture of the products, leaving 4 millions to be applied to other purposes, as burning lime, making bricks or glass, for which the gas is said to be peculiarly well adapted.

The water is easily separated from the tar which swims on its surface: it amounts to from 10,000 to 12,000 gallons from 100 tons of peat. The water contains naphtha, or pyroxylic spirit, with acetate and carbonate of ammonia in solution. Lime is added to it in the proportion of 6 cwt. to 10,000 gallons, and the ammonia, and naphtha in the rough liquor, are separated by a modification of Coffee's still, described at page 291. The mixed vapours of ammonia and naphtha, being separated from the dilute solution of acetate of lime, are passed through a close vessel containing dilute sulphuric acid, which converts the ammonia into sulphate, while the naphtha is again passed through a similar apparatus, or "rectified at once by blowing steam into it in a close safe, with a set of cups attached." The acetate of lime, or "spent-wash" from the distilling apparatus, is boiled down in large evaporating-pans of cast-iron, or boiler-plate, until the solution contains about 10 per cent of acetic acid. The crude acetate is then decomposed by sulphuric acid, and again distilled; the free acid recombined with lime, and boiled down in leaden pans to the point of crystallization.

The tar from 100 tons of peat is said to contain from 300 to 350 lbs. of paraffine, a carbohydrogen first discovered by Reichenbach in the tar of wood. This is the most valuable product from the distillation, and in order to separate it from the oils in the tar which accompany it, the latter is melted, and while at a temperature of 100° F., 20 gallons of sulphuric acid are added, and well agitated for about twenty minutes. Much of the tar is thus charred, and rendered heavier than water, and this portion, with the basic oils, sinks on the addition of hot water, while the paraffine and lighter oils come to the surface. These are distilled either by direct furnace heat or by heated steam, and the more volatile portions, about one half of the whole, collected apart from the heavier oils and paraffine. This latter portion is allowed to cool, when the paraffine crystallizes in flakes which float in a liquid oil; this is strained, and the crystalline mass is pressed to remove the oil. The paraffine is subsequently purified by chlorochromic acid, again distilled, and

pressed. It is then in a fit state for the market. Since the substance of the foregoing account, extracted from an article in Dickens's "Household Words," was published, and accredited by Mr. Reece, we have heard that chlorochromic acid has been dispensed with in the purification of the paraffine, and that oil of vitriol, and frequent distillation by heated steam, have been successfully employed. The oils which accompany the paraffine have, unfortunately, a very fœtid odour, which renders them useless in their crude condition; and they must be treated with caustic soda, or lime, and subsequently with oil of vitriol, before they can be applied to lubricating or other purposes.

Messrs. Kane and Sullivan have submitted the whole of the products resulting from the distillation of different varieties of peat, both in close vessels and by means of a blast of air, to a strict examination on a small scale, with a view to test, in the laboratory, as far as possible, the probable economic value of the process. The chemical nature of the specimens employed in this investigation will be found on a former page, under the head of "Peat or Turf." Their results, as far as the nature of the products and the quantities in which they are obtained are concerned, corroborate generally those of Mr. Reece; but they were unable to separate and purify these products by the methods he employed; nor could they obtain combustible gas at all in conducting the distillation with a blast of air, although the quantity of air admitted was varied in different experiments. It was also found very difficult to condense the products in the latter case, and to regulate the blast so as to obtain the products in any quantity: if too little force of blast is employed, a very long time is required to consume the peat, a large produce of tar, some light carburetted hydrogen, but chiefly carbonic acid gases, are obtained; if too much air is forced through the furnace, hardly any tar or liquid products are condensed, while a considerable amount of carbonic oxide is produced. It is inferred from these facts, that, if it be found necessary to produce carbonic oxide for the manufacture, no tar will be obtained; while, if the operation be conducted sufficiently slowly to form tar, it will be found impossible to obtain carbonic oxide. In every case of imperfect combustion, the aqueous liquid was acid at the end of the operation; while in closed cylinders, and when the blast was properly regulated, the alkaline reaction increased with the temperature and rapidity of the distillation. In no case was the temperature in the apparatus very high, and always quite

inadequate to flux a substance composed of the ingredients contained in ordinary peat ashes, although Mr. Reece obtained a fused slag as the residue in his process. With a proper regulation of the blast, it was found that the condensable products increased with the length of time occupied in working off the charge, and large quantities of ulmin-like resinous bodies were obtained, which it is apprehended would be liable to clog the condensing apparatus. On the whole, however, with a careful regulation of the blast, very nearly the same results were obtained with this apparatus as in the close vessels, as will be seen by the following Tables, in which the results are given, and compared with those obtained by Mr. Reece. The elementary composition of the specimens experimented upon will be found at pages 22 and 27.

TABLE I.—Representing the percentage of tar, water, charcoal, and gas, obtained from the specimens of peat subjected to distillation.

Number of Specimen.	Corresponding Number on Table, p. 22.	Locality from whence obtained.	Water.	Tar.	Charcoal.	Gas.
1	2 and 3	Mount Lucas Bog, Phillipstown	23.600	2.000	37.500	36.900
2	7	Light surface peat from the Wood of Allen ...	32.273	3.577	39.132	25.018
3	9	Black compact peat, Wood of Allen	38.102	2.767	32.642	26.489
4	4	Ticknevin.....	33.628	2.916	31.110	32.346
5	Ditto	Ditto, distilled with retort heated to redness	32.098	2.344	23.437	42.121
6	22	Upper Shannon.....	38.127	4.417	21.763	35.693
7	24	Upper Shannon.....	21.819	1.462	18.973	57.746
			219.647	19.483	204.557	256.313
			31.378	2.787	29.222	36.616

TABLE II.—Representing the percentage of the principal commercial products obtained from the distillation of peat, with the corresponding values given by Mr. Rees Reece.

Number of Specimen.	Ammonia.			Acetic Acid.			Pyroxylic Spirit, or Naphtha.		Paraffine.		Volatile Oils.		Fixed Oils.	
	Ammonia. ($N.H_3$.)	Corresponding Quantity of Sulphate of	Quantity of Sulphate of, obtained by Mr. Reece.	Acetic Acid. ($C_4H_3O_3+HO$).	Corresponding Quantity of Acetate of Lime.	Quantity of Acetate of Lime according to Mr. Reece.								
1. Phillipstown. Table, p. 22.	0.302	1.171	100 tons of peat yield 1 ton of sulphate of ammonia, = 1.00 per cent.	0.076	0.111	100 tons of peat yield 14 cwt. of grey acetate of lime, = 0.70 per cent.	0.092	Reece:—100 tons of peat yield 52 gallons, at 8 lbs. to the gallon, = 0.185 per cent.	0.024	Reece:—100 tons of peat yield 300 to 350 lbs. = 0.188 to 0.156 per cent.	0.684	According to Reece, 100 tons of peat yield about 200 gallons of oil, which, at 9 lbs. to the gallon, = 1800 lbs. = 0.803 per cent.	0.469	According to Reece, 100 tons of peat yield 98.6 gallons of oil, which, at 9 lbs. to the gallon, is = 887.4 lbs. = 0.396 per cent.
2. Light surface Peat—Wood of Allen. Table, p. 22...	0.187	0.725		0.206	0.302		0.171		0.179		0.721		0.760	
3. Wood of Allen, dense. Table, p. 22	0.393	1.524		0.286	0.419		0.197		0.075		0.571		0.565	
4. Ticknevin. Table, p. 22...	0.210	0.814		0.196	0.287		0.147		0.170		1.262		0.617	
5. Ditto distilled at full red heat	0.195	0.756		0.208	0.305		0.161		0.196		0.816		0.493	
6. Light surface Peat—Shannon. Table, p. 22	0.404	1.567		0.205	0.299		0.132		0.181		0.829		0.680	
7. Shannon, dense. Table, p. 22.....	0.181	0.702		0.161	0.236		0.119		0.112		0.647		0.266	
7)	1.872	7.259		1.338	1.959		1.019		0.937		5.530		3.850	
Average	0.268	1.037		0.191	0.280		0.146		0.134		0.790		0.550	

TABLE III.—Representing the proportions of water, tar, ash, and gas, obtained by the distillation of peat in a blast of air, with the corresponding results obtained with a closed retort.

Number.	Corresponding No. in Table, p. 22.	Locality of Specimen.	Water.		Tar.		Ash.		Gas.
			In blast of Air.	In closed Retort.	In blast of Air.	In closed Retort.	In blast of Air.	In closed Retort.	In blast of Air.
1	7	Light surface peat—Wood of Allen ...	31.678	32.273	2.510	3.577	2.493	2.745	63.319
2	9	Dense peat—Wood of Allen	30.668	38.102	2.395	2.767	7.226	7.898	59.716
3	24	Shannon—No. 4 ...	29.818	21.819	2.270	1.462	2.871	2.976	65.041

TABLE IV.—Representing the percentage of ammonia, acetic acid, pyroxylic spirit, paraffine, and oils obtained by the distillation of peat in a blast of air, and the corresponding results obtained with a closed retort.

Number.	Corresponding No. in Table, p. 22.	Locality of Specimen.	Ammonia.		Acetic Acid.		Pyroxylic Spirit.		Paraffine.		Oils.	
			In a blast of Air.	In closed Retort.	In a blast of Air.	In closed Retort.	In a blast of Air.	In closed Retort.	In a blast of Air.	In closed Retort.	In a blast of Air.	In closed Retort.
1	7	Light Surface Peat—Wood of Allen.....	0.322	0.187	0.179	0.206	0.156	0.171	0.169	0.179	1.220	1.481
2	9	Dense Peat—Wood of Allen	0.344	0.393	0.268	0.286	0.156	0.197	0.096	0.075	0.946	1.136
3	24	Shannon—No. 4	0.194	0.181	0.174	0.161	0.106	0.119	0.119	0.112	1.012	0.913
		3)	860	761	621	653	420	487	374	366	3.178	3.530
		Average	287	254	207	218	140	162	125	122	1.059	1.177

The amount of paraffine, according to these experiments, obtained from 1 ton of peat does not exceed 2¼ lbs., and yet this is the mainstay of the undertaking. Messrs. Kane and Sullivan thought it questionable whether the solid substance obtained was identical in composition with the paraffine procured by Reichenbach from beech-tar, but this was immaterial as far as the commercial value of the substance was concerned, there appearing to be no doubt that both bodies were alike valuable as material for making candles. Through the kindness of Mr. Miller, the engineer to the Peat

Company, we have been enabled to analyse a specimen of the paraffine, and have found it to contain the following elements :—

	Reece.	Reichenbach.
Carbon	84.45	85.22
Hydrogen	14.83	14.78
Oxygen, or loss . .	.72	—
	100.00	100.00

which indicates so close an approximation to that of the paraffine from beech-wood tar as to settle the point of identity: the commercial specimen not being absolutely pure, contained probably a trace of oxygenated oil.

Since the foregoing was printed, we have been favoured with the following particulars and alterations in the process by W. K. Sullivan, Esq., who has been practically engaged in experimenting at the Peat Works.

"The distillation of the peat is effected in ordinary blast furnaces, of which there are four, connected at the top by means of a platform or gallery, provided with a tramway, along which the turf is carried in waggons of sheet iron of about 30 cubic feet contents. These waggons are lifted to the top of the platform by means of an ordinary water-lift. The dimensions of each furnace are as follows: The hearth is 8 feet square; the tymp is 2 feet by 12 inches, 2 inches thick, with 2 inches of water space, and is made of cast iron. The bottom of the tymp is 18 inches from the hearth-stone. The whole height of the furnace, from the hearth to the tunnel-head or throat, is 24 feet 6 inches; the height of the boshes 6 feet; and the diameter at the belly, 12 feet. The internal diameter of the tunnel-head is 6 feet, and is covered with an iron plate, in the centre of which is a hole 3 feet in diameter, which can be closed by a kind of conical valve. This valve can be raised and lowered by means of a lever bar and chain. It has a groove all around it, into which fits, when the valve is raised, a projecting rim on the under side of the plate which covers the tunnel-head. The groove gets partially filled with turf-dust, either produced in throwing the turf into the furnace, or some is added from time to time. When the projecting rim is forced into this groove by drawing up the valve, a perfect steam-tight joint is formed.

"Upon the top of each furnace is placed a hopper in the form of

an inverted truncated cone, 5 feet high: the narrow end fits into the hole in the top of the furnace, and forms the rim just alluded to; the wide end, which is 8 feet in diameter, is capable of being closed by means of two hinged lids 3 feet 4 inches long, and 2 feet 2 inches wide. Each of these lids has a rim which fits into a grooved frame, and enables a gas-tight joint to be formed by the aid of a little turf-dust mixed with some of the blue clay marl which underlies the bog. The charge of turf is introduced into this hopper so as to fill it perfectly; the lids are closed and luted tight, and the valve in the bottom lowered into the furnace, so as to let the whole of the turf in the hopper fall into the furnace. When this has taken place, the valve is again drawn up so as to shut off the communication between the furnace and the hopper, and enable the lids of the latter to be lifted up and a fresh charge introduced. This contrivance is the chief feature of novelty in this part of the arrangements.

"The blast of air is produced by eight blowing cylinders worked by a large steam-engine.

"The products of distillation pass off from each furnace by means of two exit pipes 12 inches in diameter and about 12 feet long, that enter the furnace just under the plate which covers the top of the furnace. The exit pipes of all the furnaces discharge themselves into an hydraulic main, about 100 feet long and 3 feet in diameter; the ends of the pipes dipping 2 inches below the constant level of the liquid in the main. A considerable portion of the tar deposits in the main, from which it flows off by means of an overflow pipe, as in the usual arrangements of gas-works, and the greater part of the remainder is deposited in the condensers.

"It was in the construction of these condensers that the greatest difficulties were encountered. The system employed in the manufacture of coal-gas would not answer, for the tar of peat, unlike that obtained in the distillation of coal, at a high temperature is solid, and would block up all horizontal parts of the pipes, or all circular bends. It was therefore necessary to construct condensers in which such a result could not take place, and this has been most effectually done. The principle of the ordinary water-glass employed for bird-cages has been taken advantage of, and instead of one continued length of pipe, we have a number of separate condensers, consisting of a cast-iron box about 4 feet high, divided into two chambers by means of a diaphragm; into the top of this box, and opening into one chamber, are placed four pipes 12

inches in diameter and 22 feet high; while the other chamber has a large opening in front, and thus constitutes a kind of trough 18 inches deep. The diaphragm dividing the two chambers does not reach completely to the bottom of the box, so that there is free communication for water to flow from one chamber to another. These condenser boxes are placed side by side, and are connected one with another by means of a short pipe placed near the bottom of the trough formed by the chamber with the opening in it. Each pair of upright pipes is connected with the next pair by two breeches-pieces, the upper end or body of which is closed by a cap and screw.

"The gas and vapours entering from the hydraulic main pass from one series of pipes to the next; the condensed products being deposited as a lining upon their walls, or falling down into the chamber of the box with which the pipes are in connection. The tar gradually escapes from the inner chamber under the edge of the diaphragm, and comes to the surface of the liquid in the outer chamber, from whence it is removed from time to time in the form of soft solid lumps. The liquid in which the tar floats is also one of the products of distillation, and serves to keep the gas from escaping from the inner chamber under the edge of the diaphragm. It is always at the same level in all the condensers, in consequence of the connecting pipes just mentioned. The condensers once filled to the proper level with liquid, all that is subsequently condensed flows into a tank by means of a pipe from the bottom of the last of the series of condensers. This pipe has a syphon bend upon its course which can be raised or depressed so as to keep the liquid in the condenser, which would otherwise all flow off at any desirable level.

"The condensers, of which there are thirty-six, are arranged in two distinct rows of eighteen each; and the gas and vapours may be made to pass through both at the same time as is usual, or, in case of accident or repairs, through only one. Arrangements have been made by which a trickle of cold water may be made to flow over the condensers, should the pipes become warm. This is, however, scarcely necessary, as the temperature of the gas and vapours, as they issue from the former, is little, if at all, above 212° F. Although these condensers are amply sufficient to condense everything, with the exception perhaps of the wood-spirit and lighter oily bases, yet scrubbing must be had recourse to in order to arrest the passage of the tar, which is carried forward mechanically

by the current of air. For this purpose there are two rows of scrubbers, of four each, consisting of cylinders formed of boiler plate iron, 20 feet high and 4 feet 6 inches in diameter. Each row is in connection with one of the series of condensers, and like them may be used singly or together. These scrubbers were at first provided with three beds of coke placed upon gratings, with a space of one foot between each bed; the coke being washed by a small Barker's mill worked by means of a tumbler. But the semi-solid tar soon blocked up the interstices between the coke in the first scrubber of each row; and it was found necessary to remove the coke in the first scrubbers, and replace it by a single bed of rounded stones, and to work the mill directly by means of a strong stream of water from an inch pipe. From the scrubbers the gas passes directly to the furnaces.

"In all former experiments the tar was distilled by the direct action of the fire,—a method which was extremely objectionable. In the first place a considerable quantity was decomposed, and a large quantity of charcoal and gas produced, while the quantity of paraffine obtained was extremely small and difficult to purify, from its high colour. The oils produced were also very impure, and had so very bad a smell that they could scarcely be used for any other purpose than gas-making. In the present factory, the method by means of hot steam, proposed in the Report of the Museum of Irish Industry, has been fully adopted. The stills employed for this purpose are of cast iron, 5 feet deep and 8 feet in diameter; a vertical pipe, 4 inches in diameter, passes down through the centre of the cover, to the lower end of which is attached a T pipe of the same bore, and nearly as long as the diameter of the still. To this pipe are attached a number of arms formed of inch pipe, the whole forming a sort of gridiron. The under side of each of these arms is pierced with a number of small holes for the steam to escape through. The tar collected from the tank and condensers is first introduced into a large wooden cistern, and as it contains a large quantity of water, steam is passed into it until it becomes perfectly fluid, and the water sinks to the bottom. From this cistern it is then pumped into the still, the charge for which is about three tons. The steam, before being introduced into the still, is heated by being made to pass through a coil of pipe kept nearly red-hot by the flame of gas.

"Each charge takes about two days to work it off; the average run of mixed oils, paraffine, and water, being about fifty gallons in the

hour. About one-fourth of the products of distillation is liquid, and the remainder more or less solid; that which comes over towards the end being quite hard. There remains in the still a shining, porous, carbonaceous mass, amounting to only about five per cent of the original tar. The solid portion is kept apart in a tank, where it is heated, by means of a jet of steam, with some bichromate of potash and oil of vitriol diluted with once or twice its bulk of water, until the foreign matters are converted into a tarry resinous mass which subsides to the bottom. The mass thus purified is again distilled in another smaller still, the product placed in shallow trays of tinned iron, which are arranged on a sort of wooden framework until perfectly cold, when the solid cake is wrapped in a piece of coarse linen, or rather canvas, and pressed in an hydraulic press. The oil which is pressed out is very thick, and when very cold is semi-solid, from the formation of crystalline spangles of paraffine. The pressed cakes consist of rough paraffine. This substance is to be again treated with sulphuric acid and bichromate of potash, and subjected to one or two distillations in other stills. In the present factory there are three tar stills, one of which it is proposed should be always at work. The second distillation of the paraffine is effected in a smaller set of stills, of which there also three. Each is 4½ feet deep and 4½ feet in diameter. This set of stills is also employed for the fractional distillation of the oils, which it is proposed to purify by treatment with sulphuric acid and bichromate of potash, and then with an alkaline ley. The final distillation of the paraffine is to be effected in a still 5 feet deep and 5 feet 4 inches in diameter, which has a worm of tinned copper 100 feet long, diminishing from 4 inches to 1½ inches. The worms of all the other stills are composed of cast-iron pipes, and diminish but very little in diameter.

"The aqueous liquid produced in the distillation of the turf is pumped from the tank into which it flows from the main and condensers, into two reservoirs, each 20 feet high by 9 feet in diameter, provided with an agitator, where it is mixed with lime, in order to decompose the acetate and carbonate of ammonia, and enable the whole of the ammonia to be set free. This liquid is then subjected to distillation in a still constructed on the system long since patented by Mr. Eneas Coffee, and capable of distilling several thousands of gallons per hour. The product of this distillation, consisting of a solution of strong ammonia in a weak impure wood-spirit, is received in a reservoir, from whence a small

still on the same principle as the large one is charged. When a charge, which may be estimated at about 500 gallons, is introduced into this still, a sufficient quantity of sulphuric acid is added to neutralize the ammonia; the distillation is then proceeded with, until the specific gravity of the distillate falls nearly to that of water. The residue in the still consists of an impure solution of sulphate of ammonia: it is run into open leaden cisterns, where it is evaporated until it crystallizes. The impure wood-spirit is again distilled in a still smaller still, some lime being added to neutralize any acid. In the first distillation of the crude wood-spirit, it is usual to keep all the spirit of a higher sp. gr. than about 0.900, separate, and to return it with the next charge into the same still.

"It is expected that all the heat required for the boilers, stills, &c., will be obtained from the combustion of the waste gas. But hitherto, owing to the choking up of the scrubbers, enough of gas cannot be produced to work all the fires, as the blast cannot be increased either in quantity or intensity; the greatest pressure yet tried (measured at the tuyeres) being 1 $\frac{1}{8}$ inches of mercury. The main question has not therefore been ascertained as yet; namely, will there be as much tar produced when the pressure of the blast is increased to four or five inches of mercury, and the quantity of air doubled; and further, will that tar be as rich in paraffine as that produced at the low temperature at which the distillation has been hitherto effected under the small blast?

"The quantity of gas required to work the whole factory is considerable. There are two boilers, each 17 feet long and 6½ feet wide, with 3 feet 6 inches flue set Cornish fashion, for working the blowing engines and giving steam for working the two small stills. The boiler which works the large spirit still, the tar, and paraffine still, is 28 feet long, and is fully equal to fifty-horse power; there is also a plain circular boiler employed for working all the pumps, and giving steam to the oil stills, 16 feet long and 4 feet 6 inches in diameter. Besides these boilers, gas is required for heating the steam pipes of the tar stills, oil stills, paraffine still, evaporating pans, and may be required for a hot-blast apparatus, which has been fitted up in case it may be required. It is calculated that there will not only be gas for all these purposes, but that a considerable quantity will be to spare, which it is proposed to employ in producing peat charcoal, by heating the turf in upright cast-iron cylinders about 20 feet long. A few weeks

will fully determine the gas question, the basis of the whole scheme.

"The arrangements for burning the gas are extremely simple. There is of course no ash-pit, but a simple fire-box, into which opens the gas pipe, air being supplied by means of a number of slits in the brickwork, in which are set cast-iron frames. The large boiler for working the stills, for example, has two gas pipes 6 inches in diameter, with 4½ inch valves, for regulating the supply of gas, and two sets of slits of nine each, 7¾ inches high and ⅛ths of an inch wide. The pipe for supplying gas to the fireplace for heating the steam for the tar stills is also 6 inches in diameter with a 4½ inch valve, and the number of slits or orifices is five, each of which is 6½ inches high and 1 inch wide. The gas burns with a pale blue flame, and requires to be in large sheets in order to be ignited; it also requires to be sent into the fire-box under some pressure, say half an inch of water.

"The four furnaces are calculated to burn 100 tons of average turf in the twenty-four hours, but from the causes already alluded to, the consumption has not yet exceeded 30 tons during the same time. From the 100 tons, it is hoped that 3½ tons of tar, 1 ton of sulphate of ammonia, and from 25 to 35 gallons of wood-spirit at least will be obtained. At first it was proposed to evaporate the residual liquor from the large still containing the whole of the acetic acid in combination with lime, in order to obtain crude acetate of lime. This idea has, however, been given up, both on account of the immense quantity of water which it would be necessary to evaporate, and from the impurity of the substance which would be obtained. It would be premature to say how far these anticipations will be fulfilled, because, until the difficulties already alluded to shall have been overcome—and we believe we can venture to say that they have been—no numerical results can be obtained. For the same reason the quantity of paraffine which can be obtained from the tar cannot be accurately ascertained until the full blast be put on. If the proportion, then, be as high as the incomplete experiments made up to this time would seem to indicate, it will far exceed all anticipations, and will certainly be five times greater than that obtained by the old method of distillation over the naked fire.

"As no paraffine or oils have yet been fully purified, no opinion can be given as to whether their final purification will present any peculiar difficulties. None are, however, anticipated; indeed,

the rough oils are quite different bodies from those formerly obtained, and do not, comparatively speaking, smell very badly.

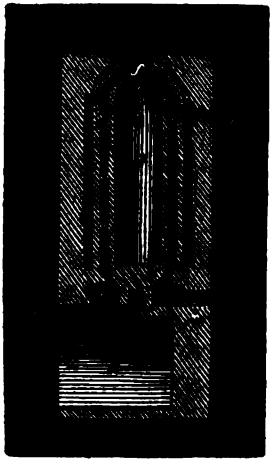
"The system of cutting the turf is not as yet very perfect, but considerable improvements are being gradually introduced. It is all cut by contract, at the rate of 3½*d.* per 24 cubic feet of dried turf delivered at the foot of the furnace. The company pay the rent of the bog, do all the drainage work, make the canals by which the turf is brought from the centre of the bog to the works, which stand upon its edge, and provide the boats in which it is brought. Taking all these items into account, the turf costs at the furnace on an average from 2*s.* 2*d.* to 2*s.* 6*d.* per ton."

Mr. Sullivan adds: "The improvements commenced when I was at Athy have been attended with great success. These consist in making the gas pass through four rows of two scrubbers, instead of making it pass through two rows of four scrubbers: by this means a greater space is given for the passage of the gas; the layer of stones has also replaced the coke in the first set of scrubbers. Since this improvement was effected, it appears that gas enough to work the whole factory can now be obtained regularly without any apparent diminution in the production of tar. Another part of the improvement consisted in enlarging the coil of pipes by which the steam admitted into the tar stills is heated. The effect of this change is to greatly diminish the duration of a distillation of tar. The gas pipe leading to the large boiler has also been enlarged, so that a better supply of steam can now be obtained for working the tar stills. On the whole, the ameliorations now effected appear to have greatly increased the probability of success of the process."

Paraffine.—Paraffine is a pure white solid substance, resembling wax when melted in small quantities; but when cooled slowly in large masses, and quite pure, the crystalline scales become aggregated together, and it presents very much the same appearance as spermaceti: it has no taste nor smell, and feels soft and soapy between the fingers. Paraffine melts at 112° F., and can be distilled at a higher temperature without decomposition; it burns without producing smoke, and hence is admirably adapted, either alone or mixed with other fats, to the manufacture of candles. Its specific gravity is 0.870. Its name is derived from *parum affinis*, and is indicative of the want of affinity it exhibits to most other bodies. It resists the action of all the strong acids, alkalies, chlorine, and potassium.

An excellent oven for charring peat and collecting the volatile products, has been erected at Courcy-sur-Ourcq, near Meaux, which consists of a cylindrical retort *a*, heated by the flues *b*; and in order to maintain the temperature as uniform as possible, there are open spaces *d* left in the wall, filled with air. The flames ascend from the fireplaces *c*, and the smoke passes off through an opening in the metal plate *g* on the top. The peat is thrown in at *e*, and when full is closed by a strong cast-iron plate *f*, which is covered with sand and ashes, over which the smoke from the fire passes. The gaseous products escape by a pipe *l* to the condenser, and when the operation is finished the charcoal is drawn out into a pit *k* through the bottom of the retort, which consists of an iron damper *h*, which can be moved from the outside.

FIG. 218.



Production of Paraffine Oil, Naphtha, and Paraffine, from Boghead Coal.—Some varieties of coal, particularly those which afford the largest amount of illuminating gas, as the Parrot, Cannel, and Boghead coals, have been latterly distilled for the sake of the naphtha and oils which they afford at a low temperature, and a patent was obtained by Mr. J. Young for a process by which large quantities of paraffine and paraffine oil are obtained from them. The coal principally employed in this manufacture is that found at Bathgate, in Scotland, and known as Boghead coal, the constitution or nature of which has recently given rise to great difference of opinion among scientific men, some considering it a bituminous shale, while others view it as a true coal. We shall have occasion to recur again more particularly to the composition and physical properties of this remarkable mineral, and merely add its average composition, as follows:

Earthy matter	20	to 25	per cent.
Total carbon	60	„ 65	„
Hydrogen	7½	„ 9	„

Of the carbon, only from 6 to 16 per cent is fixed, or remains in the retort after distillation, owing to the large amount of hydrogen, which is greater in this than in any other variety of coal. In pre-

paring the paraffine oil, now most extensively used for lubricating machinery, the coal is broken into small pieces, and distilled in an ordinary gas-retort, connected with a worm-pipe passing through a refrigerator, and kept at a temperature of 55° F. by a stream of cold water. At a lower temperature the pipe is liable to be clogged, in consequence of the solidification of the paraffine. The retort being charged, is gradually raised to a dull red heat, at which temperature it is kept as long as volatile products escape. An increase of temperature is prevented, which would convert the otherwise condensable products into permanent gases, which, to some extent, always escape, and may be collected or burned.

The crude paraffine oil obtained in the distillation is heated to 150° F. by means of a steam pipe, when water and mechanical impurities separate, and the oil, having been kept warm for twenty-four hours, can be run off into another vessel, leaving the foreign matters behind. The oil is then redistilled in an iron vessel, and connected with a condenser kept at a temperature of 55° F. as before. Nearly the whole passes over, leaving a small carbonaceous residue. From the condenser the oil flows into a leaden vessel, where 10 gallons of oil of vitriol are mixed with every 100 gallons, by constant agitation for an hour. It is then left at rest for twelve hours, during which time the acid, and the substances it has extracted, settle to the bottom of the vessel. The oil is then drawn off into an iron vessel, and mixed with caustic soda of sp. gr. 1.3, 4 gallons of this solution being added to every 100 gallons of oil. Agitation is again kept up for an hour, and again the whole allowed to settle during six or eight hours, when the oil is removed from the alkaline solution, and again distilled with about half its bulk of water, which relative proportions are kept constant by the addition of water during the distillation. The steam carries over with it an oil or naphtha lighter than paraffine oil, which separates as it leaves the worm, coming to the surface of the condensed water. This oil or naphtha may be employed for illuminating purposes. The oil remaining in the still is separated carefully from the water, and again treated in a leaden vessel, with about 2 gallons of oil of vitriol to every 100 gallons of oil, constant stirring being kept up for six or eight hours, and then left for twenty-four hours to allow the acid to settle down. This oil is agitated with chalk, ground up into a thin paste with water, 28 lbs. of the paste being added to every 100 gallons of oil. In this manner every trace of sulphurous acid, which is copiously evolved during the action of

the vitriol, is removed, and the oil kept at 100° F., for about a week. This is necessary, to separate the impurities. The oil is then fit for use, as a lubricating agent, or for illuminating purposes, either alone, or mixed with fat oils.

To obtain solid crystalline paraffine, which is contained in solution in this oil, the oil is cooled as much as possible, when crystals of paraffine are formed, and may be separated from the liquid oil by filtration through woollen cloths. The lower the temperature, the greater the amount of solid paraffine which separates. The crystals are collected and submitted to pressure, that the last portions of oil may be squeezed out. In order to obtain the substance perfectly pure, it must be treated once or twice with its own bulk of oil of vitriol, washed subsequently each time with caustic soda, and lastly with pure warm water. The solid substance thus obtained is admirably adapted for making candles; but the last processes of purification are too costly to admit of its being manufactured for that purpose at present.

The analysis of paraffine from Boghead coal, for a specimen of which we are indebted to Mr. Young, yielded the following result:

Carbon	84.4
Hydrogen	14.87
Loss, or oxygen . . .	0.73
	100.00

William Brown distils coal or bituminous substances with steam, heated by passing through a coil of red-hot pipe, and obtains in this manner a large amount of paraffine. The crude products from the first distillation are submitted a second time to distillation in a similar apparatus, when a light oil, paraffine oil and paraffine, are separately collected. The light oil is purified by heating to 212° F., with from 5 to 10 per cent of vitriol, and an equal bulk of water, to which bichromate of potash is added in the proportion of one-half of the vitriol employed. The oil is subsequently agitated with a warm solution of caustic soda.

The heavy or paraffine oil is purified in the same manner, and distilled again, the lighter portions of the distillate being collected separately, and the last portions added to the paraffine. Bag filters, and subsequent hydraulic pressure, are employed to separate the oil from the paraffine, which is then treated, at a temperature of 400° F., with $\frac{1}{20}$th to $\frac{1}{10}$th of its weight of strong vitriol, and lastly with water, or a dilute solution of soda.

Paraffine and Oil from Bituminous Shale.—Various kinds of oil and paraffine were obtained by Seligue, some years ago, in France, by distilling the bituminous shale of Autun; and similar products have been extracted from the shale of Dartmoor, in the west of England. The manufacture in the latter locality has been discontinued for reasons with which we are not acquainted, while Wiesman and Co. are successfully working Seligue's process at Beul, near Bonn, on the Rhine. The factory at Beul produces paraffine, which, at two shillings per pound, is capable of competing with wax and spermaceti; a volatile oil of sp. gr. 0.730, adapted for cleaning clothes, gloves, and used also as a solvent for resins, and for mixing with other less volatile products, to form a good burning oil, of sp. gr. 0·830, for camphine lamps. This oil is sold at something less than four shillings per gallon. Fixed oils are likewise obtained, which can be rendered drying, and used as paint, or burnt for the production of lamp-black. Asphalt and coarse cart-grease are also manufactured from the products of the distillation.

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